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A PROGRAM OF SOLAR RESEARCH.[1]

BY GEORGE E. HALE

In an article on "Solar Research at the Yerkes Observatory"[2] I have given, in outline, a program of solar investigations prepared several years ago. Some of the investigations included in this program were carried out at the Yerkes Observatory, and others are still in progress there. As explained in another paper,[3] it was found that the solar spectrograph attached to the 40-inch telescope was of insufficient focal length for satisfactory photographic work on the spectra of sun-spots, and accordingly this work was postponed, and has recently been taken up at the Solar Observatory. For similar reasons it was found to be advantageous to delay other investigations until the completion of the Snow telescope. We are finally in a position, however, to attack the whole question seriously. I have therefore thought it might be of interest to publish the revised program of solar research which we are putting into operation on Mount Wilson.

In preparing this program, two principal purposes have been considered: (1) the study of the Sun as a typical star, with special reference to stellar evolution; (2) the study of the Sun as the central body

[1] *Contributions from the Solar Observatory*, No. 3.

[2] *Astrophysical Journal*, **16**, 211, 1902.

[3] *Contributions from the Solar Observatory*, No. 5: "Photographic Observations of the Spectra of Sun-Spots."

of the solar system, with special reference to the relationship between solar and terrestrial phenomena.

The proposed investigations include:

I. DIRECT PHOTOGRAPHY

a) Daily photographs of the Sun on a scale of 6.7 inches (17 cm) to the diameter, for comparison with spectroheliograph plates.

b) Large-scale photographs of spots and other regions, for the study of details.

II. PHOTOGRAPHIC STUDIES OF THE SOLAR ATMOSPHERE WITH THE SPECTROHELIOGRAPH

a) Daily photographs of the Sun with the lines:

(1) H_1, showing the calcium flocculi at low level.

(2) H_2, showing the calcium flocculi at higher level.

(3) H_2, showing the calcium flocculi at higher level and the prominences (composite photographs, with separate exposures for flocculi and prominences).

(4) $H\delta$, showing the hydrogen flocculi.

(5) Other dark lines, as may prove feasible, showing the flocculi of the corresponding elements.[1]

b) Measurement and discussion of the above photographs, involving:

(1) Determination of the area of the flocculi and their distribution in heliographic latitude and longitude. These results will give a measure of the relative activity of different elements in various regions of the solar surface; furnish the means of answering certain questions regarding the relationship of flocculi to spots, such as the time of first appearance, relative position on the disk, etc.; and serve for comparison with meteorological and magnetic records.

(2) Measurement of the heliocentric position of points in the flocculi that can be identified on several successive photographs, to determine the law of the solar rotation for the corresponding elements.

(3) Determination of the position, area, and brightness of eruptive phenomena, to find whether they are related to other phenomena of flocculi or spots, to possible changes in the

[1] λ 4045, showing the iron flocculi, is now used daily.

absorption of the solar atmosphere, and to auroras and magnetic storms.

(4) Measurement of the area and brightness of the neutral or bright regions near sun-spots, on photographs of the hydrogen flocculi, for comparison with other phenomena, such as the velocity of ascending and descending currents of calcium vapor, the intensity of radiation (for given wave-lengths) of the spots and neighboring regions, etc.

(5) Study of the motion of the high-level calcium vapor, especially in flocculi overhanging sun-spots, to determine the direction and velocity of horizontal currents.

(6) Measurement of the position and area of prominences, and study of their relationship to solar and terrestrial phenomena.

c) Special studies with spectroheliographs of suitable dispersion, involving the use of various dark lines (including enhanced lines) and of lines affected in spots; simultaneous photographs of eruptions on the disk in different lines; comparative studies of quiescent and eruptive prominences with the hydrogen and calcium lines, etc.

III. SPECTROSCOPIC INVESTIGATIONS

a) Daily photographs of the spectra of spots, region $H\alpha$ to $H\beta$, for the determination of intensities and the identification of lines that are widened or otherwise affected.[1]

b) Photographs of the H (or K) line, with high dispersion, on successive sections of the disk, to give the radial velocity of the calcium vapor in the flocculi, chromosphere, and prominences.

c) Measurements with the bolometer of the relative radiation, corresponding to various wave-lengths, of the sun-spots, faculae, and photosphere; and bolographs of spot spectra.

d) Spectrographic measurements of the solar rotation, to determine the law of rotation with the lines of various elements, and to detect possible changes in the rotation period. (See also II, *b*), 2.)

e) Miscellaneous investigations, as opportunity may offer, of the

[1] These photographs may also serve to record such exceptional phenomena as the remarkable disturbance of the reversing layer described in a previous paper (*Astrophysical Journal*, **16**, 220, 1902).

spectrum of the chromosphere; the pressure in the solar atmosphere, etc.

IV. STUDIES OF THE TOTAL SOLAR RADIATION

a) Frequent determinations of the total solar radiation, involving measures with the pyrheliometer at various altitudes of the Sun, and simultaneous bolographic records to give the absorption of the Earth's atmosphere.

b) Frequent determinations of the absorption of the solar atmosphere for light of various wave-lengths, to detect any possible changes in absorption that might account for observed changes in the total radiation.

c) Occasional supplementary observations on Mount San Antonio, (24½ miles = 39.4 km from Mount Wilson) at an altitude of 10,100 feet (3,050 m).

d) A comparative study of different types of pyrheliometers.

V. LABORATORY INVESTIGATIONS

a) A study of the lines affected in sun-spots under various conditions of temperature, pressure, etc.

b) Determinations of the pressure-shifts of certain solar lines.

c) Other similar investigations.

With a few exceptions, these investigations are now in progress at the Solar Observatory. Direct photographs of the Sun are taken daily, but large-scale photographs of details have not yet been started. The daily spectroheliograph routine includes H_1, H_2, $H\delta$, and λ 4045 (*Fe*) photographs of the disk, and H_2 (composite) photographs of the flocculi and prominences, all on a scale of 6.7 inches to the Sun's diameter. (See *Contribution* No. 7.) Special studies with the spectroheliograph are also in progress. An account of the work on spot spectra and on the motion of the calcium vapor may be found in *Contributions* Nos. 5 and 6. Special apparatus for the spectrographic study of the solar rotation has been nearly completed in our instrument shop. The study of the solar radiation has so far been confined to the investigations of the Smithsonian Expedition (June–November 1905), but arrangements have been made to continue this work next year. In the laboratory an investigation has been undertaken of the effect of a magnetic field on lines that are widened in sun-spots.

There are many solar investigations not included in this program which offer important returns to careful observers. In visual observations attention may well be directed to such matters as the brightness of the inner extremities of the penumbral filaments; the relative width of these filaments in large and small spots; the evidence for and against cyclonic motion in spots; the changes in the peculiar patterns frequently assumed by the photospheric granules; the character of the granulation in the faculæ, etc. Large-scale photographs, like those of M. Janssen, may also be used in the study of such questions, but the most minute phenomena can be observed only visually. The chromosphere and prominences offer an excellent field for the visual study of details, in addition to the statistical studies of the Italian spectroscopists and other observers, which should be continued and extended. At times of good definition, the spectrum of the chromosphere will richly repay observation with powerful instruments. The same may be said of spot spectra, where many observers can find profitable employment.

The above investigations are mentioned merely as examples of the innumerable opportunities open in solar research. As I hope to show at some future time, the amateur, even if his instrumental equipment be a very modest one, may do work of the highest value, if he will plan it intelligently. A careful consideration of the requirements of promising researches, and a willingness to co-operate with others, should enable any observer to contribute in an important way to the progress of solar physics.

Mount Wilson,
December 1905.

SOME TESTS OF THE SNOW TELESCOPE[1]

By GEORGE E. HALE

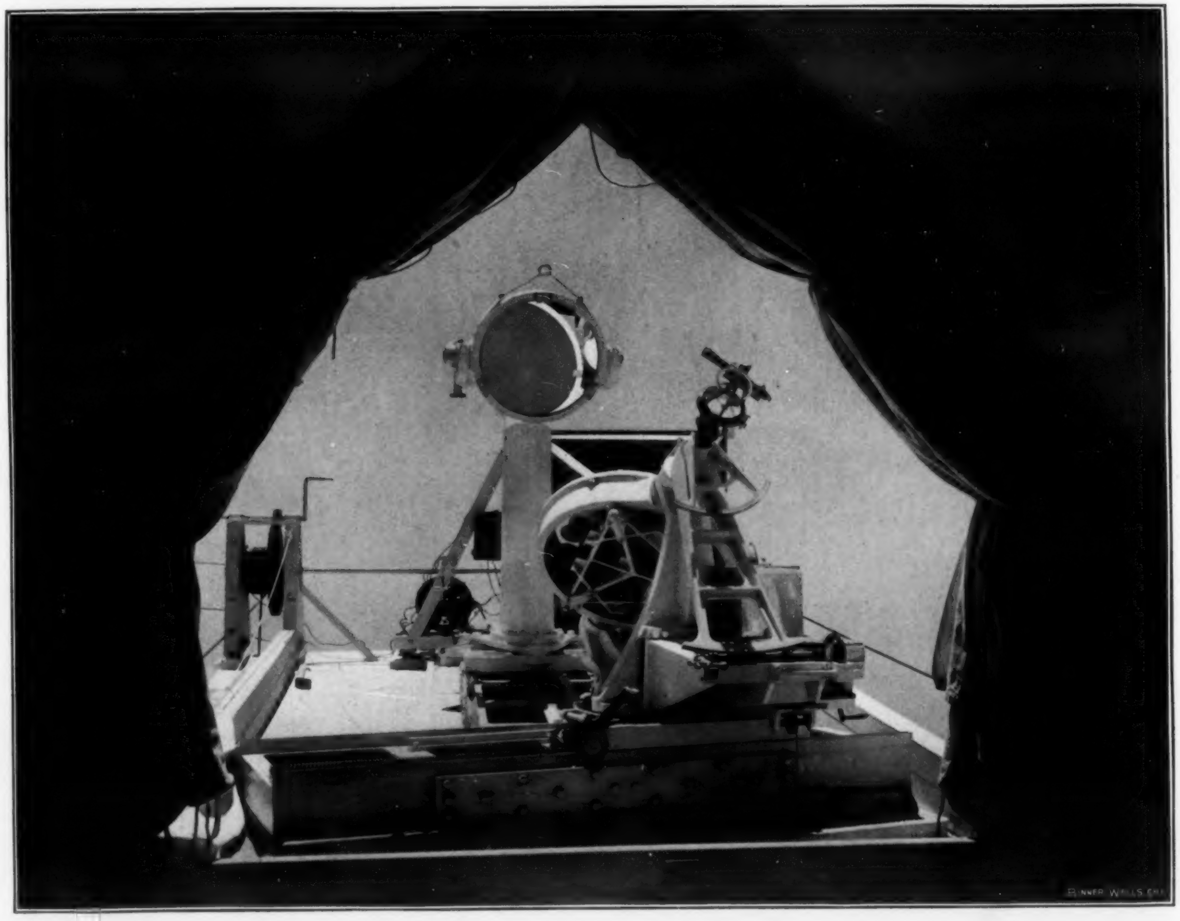
In *Contributions from the Solar Observatory*, No. 2, I have given a brief description of the Snow telescope and the house in which it is mounted on Mount Wilson. At the time that paper was written the telescope was not yet in working order, and it remained to be determined whether it would prove capable of giving the results expected from it. I am glad to say that it has since been completed and successfully used in a variety of work. It is believed that an account of the experience so far gained with this telescope may be of service to others who may intend to use similar instruments.

The cœlostat and second mirror are shown in Plate I, a view taken from within the sliding shelter which covers these parts of the instrument when not in use. The cœlostat mirror is 30 inches (76 cm) in diameter, and the second (plane) mirror, which sends the beam from the cœlostat to the concave mirror in the north end of the telescope house, has a diameter of 24 inches (61 cm). The second mirror can be moved along rails, so as to receive the reflected beam from objects at different declinations. The cœlostat and second mirror stand on a stone pier 29 feet (8.8 m) high at its south end and 25 feet (7.6 m) high at its north end. A house, of steel construction covered with canvas louvres, surrounds the pier and affords space in the extension toward the north for the concave mirrors and the spectroheliographs and spectroscopes. The concave mirror, shown in Plate II, has an aperture of 24 inches and a focal length of 60 feet (18.3 m). A second concave mirror of the same aperture and of 143 feet (43.6 m) focal length is under construction in our optical shop, and will soon be mounted in the long extension of the house which lies beyond the canvas partition now temporarily in place near the 60-foot mirror.[2]

[1] *Contribution from the Solar Observatory*, No. 4.

[2] For a plan and elevation of the Snow telescope house, together with photographs showing its manner of construction, and a further account of the instrument, see *Contributions from the Solar Observatory*, No. 2, and the *Report of the Director of the Solar Observatory for the Year Ending September 30, 1905*.

PLATE I



Coelostat and Second Mirror of Snow Telescope

PLATE II

Concave Mirror of Snow Telescope

In the preliminary tests of the Snow telescope at the Yerkes Observatory, the results were rather disappointing, though good images were occasionally obtained. It was evident that difficulty might be expected from the distortion of the mirrors by the Sun's heat, and in the first experiments on Mount Wilson this expectation was realized. Soon after the exposure of the mirrors to the Sun it was seen that the focal length was increasing, and, as the focus changed, evidence of the astigmatism of the mirrors made itself apparent in the appearance of the image inside and outside the focal plane. Since the change of focus amounted in some cases to as much as 12 inches (30.4 cm), and since the astigmatism under such circumstances was very marked, it was feared that great difficulty would be experienced in the use of the telescope, particularly as the focus at opposite limbs of the Sun on one occasion differed by as much as 3 inches (7.6 cm). The changes of focal length at different times did not seem to be the same, even for equal altitudes of the Sun. This was soon traced to the change in the amount of heat absorbed by the mirror as the silver film deteriorated in use. Another variable, as subsequent experiments proved, was introduced by the strength of the wind and the temperature of the air blown across the mirror surface. On a day with a cool breeze the focus changed less than on a day with no wind. Naturally enough, the height of the Sun above the horizon proved to be a very important factor, so that the focus changed much more rapidly near noon than early in the morning.

From the outset, the advantages of observing the Sun during the early morning hours had been apparent. In view of the difficulties that were being experienced, this point was again carefully investigated, and it was soon found that with the Snow telescope the finest definition is to be expected about one hour after sunrise. At this time the mountain is but little heated, and the atmospheric absorption reduces the intensity of the solar radiation to such a degree that the mirrors change their figure slowly. If the mirrors are shielded from sunlight between exposures of photographs, and if the exposure time is made as short as possible, excellent results can be obtained

during a period of about an hour in the early morning, and usually during a similar period not long before sunset.

It must be understood that the precautions mentioned are necessary only when it is desired to secure the finest possible definition of the solar image. When such precautions are used, the average photographs taken during the summer in the early morning with the Snow telescope and temporary spectroheliograph are but little inferior to the best photographs, secured on only a few days in the year, with the 40-inch Yerkes telescope and the Rumford spectroheliograph. The best photographs taken on Mount Wilson are distinctly superior to the best ever secured by Mr. Ellerman and myself with the 40-inch telescope. Unless these points were made clear, it might be supposed that no work could be done with the Snow telescope except under the conditions stated. As a matter of fact, however, very fair photographs can be obtained with the spectroheliograph at almost any time during a cool day, and in the early morning and late afternoon hours of a hot day without wind. It is only necessary to arrange the daily program of observations so that the spectroheliograph, which requires the finest definition, is used during the period when the seeing is best. Photographic work on the spectra of sun-spots follows, and after this is completed the conditions are entirely satisfactory for various other observations, such as bolographic work on the absorption of the solar atmosphere, etc.

The photographs reproduced in Plate III will give an idea of the results obtained with the Snow telescope. The spectroheliograph employed was put together for temporary use pending the completion of the permanent instrument. The only prisms available were some that had proved unsuitable (because of poor definition) for the Bruce spectrograph, and the slits were taken from old instruments. The optical train was mounted on a wooden platform, with cast-iron Λ-rails running on four steel balls resting on cast-iron V-rails attached to a wooden base. A small electric motor, belted to a pulley on the end of a long screw, provided the motive power. The screw was mounted on the wooden base, and passed through a nut attached to the platform. The numerous photographs obtained with this simple and inexpensive apparatus have served for a comparative study of the faculæ and the H_1 flocculi.

PLATE III

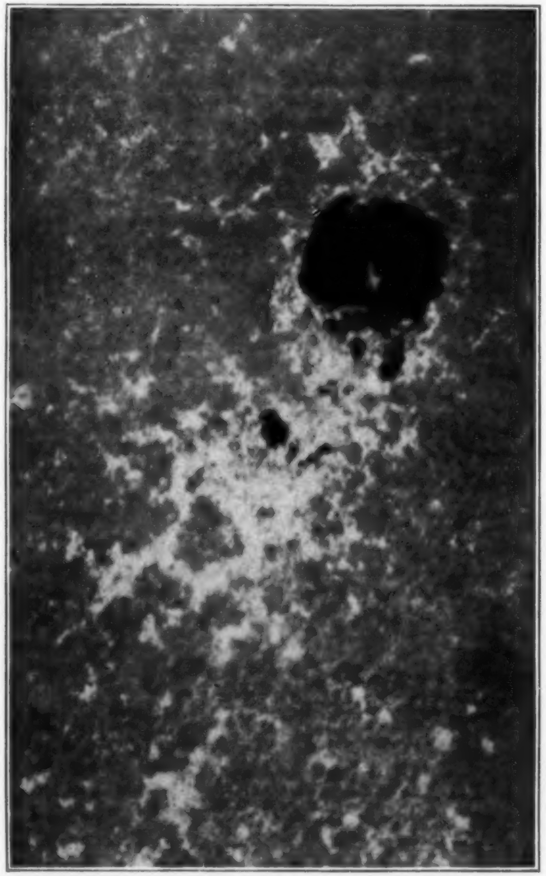


FIG. 1

July 17, 1905, 17^h 56^m. Low-Level Calcium Flocculi Slit Set on H_1 ($\lambda 3966$). Sun's Diameter =0.28 meter.

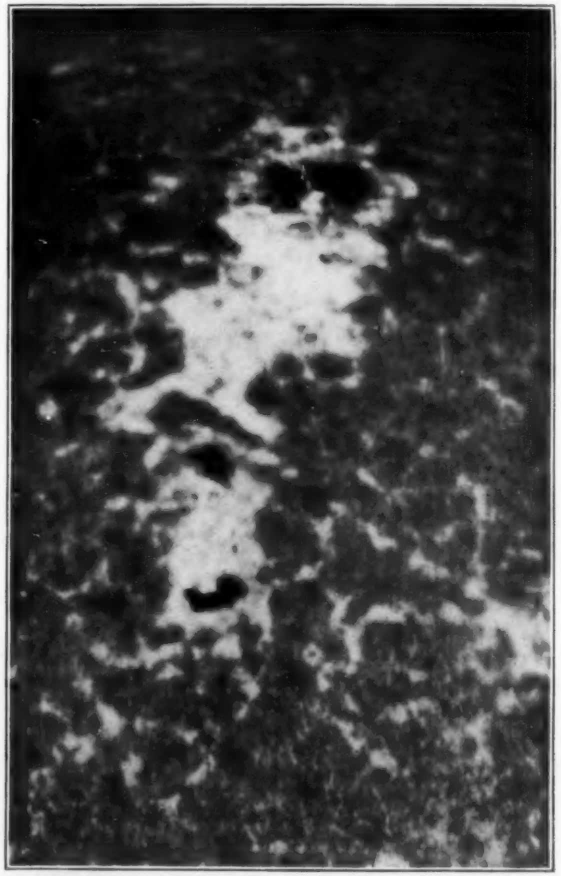


FIG. 2

July 20, 1905, 5^h 18^m. High-Level Calcium Flocculi. Slit set on H_2. Sun's Diameter=0.28 meter.

The ventilated house provided for the Snow telescope has proved so satisfactory that it has not seemed necessary to make further experiments on the use of Langley's method of stirring the air along the path of the beam. It is usually found best to lower the inner canvas wall on the side of the house away from the Sun, leaving the canvas wall on the opposite side of the house in place, so that the heated air under the louvres may pass upward and out through the ventilated roof, instead of entering the house and disturbing the beam (see Plate II).

While fans have not been employed for stirring the air, they have nevertheless been used to advantage in blowing the mirrors, for the purpose of preventing a rapid change of figure. In the first experiments, a fan 4 feet in diameter, driven by an electric motor, was mounted at the south end of the cœlostat pier. Air from this fan was led to the cœlostat mirror and the second mirror through large canvas tubes. In these experiments the concave mirror did not receive a blast of air, as it was thought the effect could be detected sufficiently well if only the first and second mirrors were cooled in this way. As it was found that the focus could be varied through a considerable range by blowing the first two mirrors, arrangements have been made to cool all the mirrors in the same way. The small electric fans to be used for this purpose will be operated while the adjustments of the spectroheliograph are being made, and also between exposures, when the mirrors are also shielded from the Sun by an adjustable canvas screen.

Excellent definition is obtained at night with the Snow telescope, except when the mirrors have been exposed to the Sun for some hours during the afternoon. On such occasions the rapid change of figure during the early evening results in irregular distortions, as indicated by the multiple images sometimes observed. Without such previous exposure to the Sun, the images of the stars and of the Moon leave nothing to be desired. Nevertheless there is a considerable change of focal length during the night, but this would be inappreciable during short exposures, and during long exposures on stellar spectra it is only necessary to correct the focus by changing the position of the concave mirror from time to time.

It is to be hoped and expected that materials more suitable than glass can be obtained for the mirrors of telescopes which are to be used for solar work. Some preliminary tests of small mirrors of "Invar" (nickel-steel of the lowest coefficient of expansion), made by Hilger, indicate that this material can hardly be used, since it is too soft, in Professor Ritchey's opinion, to permit a large optical surface, even if once produced, to be kept well polished and free from scratches. It is probable that speculum metal could be used with a fair degree of success, since such a good conductor of heat would presumably act very differently from a poor conductor like glass. I am informed by Mr. Brashear that when speculum metal grating-plates are being figured, tests can be made very much sooner after polishing than is possible in the case of glass. This indicates that the figure is changed less by the heat produced by friction. Our attempts to produce disks of fused quartz have not yet been successful enough to demonstrate that mirrors can be made of this material.

From a mechanical standpoint the Snow telescope has proved to be completely successful. From an optical standpoint it has shown itself capable of giving results with the spectroheliograph superior to those obtained in our work with the 40-inch refractor. In view of the advantages it offers for many classes of astrophysical research, this telescope may now be considered to have passed the experimental stage, though the possibility of providing better material for the mirrors indicates that its optical performance will probably be considerably improved in the future.[1]

MOUNT WILSON, CALIFORNIA,
November 1905.

[1] For an account of recent work with the Snow telescope, see *Contributions*, Nos. 5, 6 and 7.

PHOTOGRAPHIC OBSERVATIONS OF THE SPECTRA OF SUN-SPOTS[1]

[1] *Contributions from the Solar Observatory*, No. 5.

By GEORGE E. HALE and WALTER S. ADAMS

INTRODUCTION

In the *Astrophysical Journal*, **16**, 217, 1902, an account is given of experiments in photographing the spectra of sun-spots made at the Yerkes Observatory in 1902. The spectrograph employed in this work was provided with collimator and camera of 3¼ inches (8.3 cm) aperture and 42½ inches (108 cm) focal length, and a plane grating having 20,000 lines to the inch (7,874 to the centimeter), used in the second spectrum. With the same spectrograph the more conspicuous of the widened lines had been photographed at the Kenwood Observatory some years previously, but the 2-inch (5 cm) solar image given by the 12-inch (30 cm) Kenwood refractor was found to be too small for satisfactory work. At the Yerkes Observatory the spectrograph was attached to the 40-inch (102 cm) telescope, and the 7-inch (18 cm) solar image proved to be large enough for all but the smallest spots. Many widened lines were photographically recorded, and the spot "bands" were partially resolved into lines, some of which were measured on the plates. The linear dispersion of the spectrograph, however, was quite insufficient to permit more than a small part of its resolving power to be realized photographically. For this reason the continuation of the work was deferred until a suitable spectrograph could be obtained. Since this instrument was to have a focal length of 18 feet (5.5 m), it could not be attached to the 40-inch telescope. For this reason it was decided to carry on the work with a long-focus horizontal telescope, then in process of construction in the instrument shop of the Yerkes Observatory.

INSTRUMENTS EMPLOYED

The experiments were resumed last August on Mount Wilson, with the aid of the Snow telescope, which gives a solar image 6.7 inches (17 cm) in diameter when the concave mirror of 24 inches

(61 cm) aperture and 60 feet (18.3 m) focal length is employed. In some of the experiments the image was enlarged to a scale of 16 inches (41 cm) to the Sun's diameter, by means of a Brashear concave amplifying lens; but while good results were obtained in this way, it was thought best to use the 6.7-inch image until the completion of the 24-inch mirror of 143 feet (45.7 m) focal length, which will give a 16-inch solar image without amplification.

The 6-inch (15 cm) objective of 18 feet (5.5 m) focal length for the Littrow (auto-collimating) spectrograph was under construction by the Zeiss Co., and no large grating was available. We were fortunate, however, in having the use of a 4-inch (10 cm) visual objective of 18 feet focal length, and a 4-inch grating, having 14,438 lines to the inch (5,672 to the cm), both belonging to the Yerkes Observatory. The slit of the Littrow spectrograph is mounted immediately below the photographic plate, to which the spectrum is returned by tilting the grating back through a very small angle. Light from the slit reflected toward the plate by the 4-inch objective is eliminated by pasting small pieces of paper to the inner surface of the lens. The plate-holder can be moved vertically by means of a rack and pinion, thus permitting several spectra to be photographed side by side on a single plate $3\frac{1}{4} \times 10$ inches (8.3×25.4 cm). As the distance from the center of the slit to the center of the spectrum is only $5\frac{3}{4}$ inches (14.6 cm), the astigmatism, which is at right angles to the direction of dispersion, is too small to be noticeable. The definition of the spectrograph is excellent visually, but in view of the comparatively long exposures required in the third-order spectrum, the present work has been done in the second order, where the linear dispersion is insufficient to secure complete photographic resolution. For this reason we hope to obtain better results when a larger objective and grating have been provided for the spectrograph.

At this point a few words may be said regarding the relative advantages of the visual and photographic methods of observing spot spectra. The visual method permits the finest details of the spectra to be seen, and thus renders possible the separation of close ines and the observation of such narrow reversals as Mitchell has recently recorded. Advantage can be taken of the moments of best

definition, and none of the various phases of rapidly changing eruptive phenomena need be lost, as they may be in photographic work where exposures of several minutes are required. For these reasons visual observations cannot be wholly supplanted by photography, in spite of the numerous advantages of the latter. These include:

1. The possibility of recording, during brief periods of fine definition, the entire spectrum of several spots, leaving the work of measurement and identification of the lines to be done at leisure.

2. The high degree of precision attainable in measurements o- the photographs, insuring correct identification of lines and the detection of small displacements caused by motion or pressure.

3. The ease of acquainting other observers, through the publication of photographs, with the exact nature of the results obtained, thus reducing the danger of such misunderstandings as are common in connection with visual work.

The plates used in our work are the Cramer Instantaneous Isochromatic, which have a maximum of sensitiveness at about λ 5600. With suitable exposure-time these plates cover the region from near the D lines into the blue-green. It would, of course, be possible to go farther to the red by extending the time of exposure sufficiently, but the curve of sensitiveness in this region is so steep that only a very small extent of spectrum would be properly exposed at any one time; and so it has seemed preferable to wait until specially sensitized plates become available for this work. The region which we include in our present discussion extends accordingly from λ 5000 to about λ 5850.

Table I gives in detail Mr. Adams' estimates of intensity and identifications with Rowland's solar lines for the widened lines upon ten of the plates, L 17 . . . . L 43. The individual determinations of intensity are given in order to show about what degree of accordance is to be expected among separate observations. As stated above, we have adopted Fowler's plan of estimating the spot lines in terms of Rowland's intensities, beginning with 0000, which represents a line at the limit of visibility, and going upward through 000, 00, 0, 1, etc. Intermediate intensities are denoted by a dash between the preceding and the following value: thus, 1–2 denotes a line whose intensity is

midway between 1 and 2 of Rowland's scale. In practice this system has proved very convenient. The spectrum of the spot has on either side the spectrum of the disk for comparison purposes, the intensities of the two having been made as nearly as possible the same through suitable exposure time. Accordingly, in examining the plates under a low-power microscope, the observer has in the same field of view with the spot spectrum a large number of lines of the comparison spectrum showing a wide range in intensity. The estimation of the intensities of the spot lines in terms of these then becomes very simple.

The first three columns of the table give Rowland's wave-lengths for the lines, the elements to which they are due, and their intensities in the Sun. The fourth column gives their intensities in the spots and is made up of the means of the succeeding columns. It is placed next to the column of Solar Intensities for convenience in comparison. The abbreviation "n. c." for "no change" denotes that the line is not affected.

The linear scale of the plates is very closely 1.5 tenth-meters to the millimeter.

The list below does not include lines for which the mean of the determinations does not show a change of intensity amounting to one-half of a division on Rowland's scale. It also omits a considerable number of "band-lines" in the region λ 5300 to λ 5600, which we are at present engaged in identifying, and shall publish later. The "band-lines" in the region λ 5000–λ 5200 are discussed elsewhere in this paper.

Visual determinations of the widened lines in this region of the spectrum have been published by many observers. The latest of these is that of W. M. Mitchell,[1] and a comparison of the results obtained by the two methods is of considerable interest. It should, however, be remembered that the list of lines given here is based upon but ten plates, and that these include only three separate spots, while Mitchell's results are derived from a much greater number. Excluding the "band-lines" in the region λ 5030–λ 5215, Mitchell's list gives a total of 352 lines between λ 5000 and λ 5850 which are affected. The table above gives a total of 345. Of these, 267 are common to both lists; 85 are given by Mitchell which do not occur in our list; and 78 are given above and are not found in Mitchell's table. The

[1] *Astrophysical Journal*, **22**, 4, 1905.

TABLE I

Lines Affected on the Photographs

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5009.83	*Ti, Co*	00	1–2				1–2	1–2						
5013.48	*Cr, Ti*	2	2–3				2–3	2–3						
5016.34	*Ti*	2	3				3	3						
5017.76	*Ni*	3	3				n. c.	n. c.						Winged
5020.21	*Ti*	2	3				3	3						
5021.78	*Fe*	0	1				1–2	0–1						Hazy
5022.11	*Cr*	000	0				0–1	0						
5023.05	*Ti*	2	2–3				2	3						
5025.03	*Ti*	3	4				4	4						
5025.75	*Ti*	1	2				2	1–2						
5027.30	*Fe*	3	4				4	4						Rowland's intensity poor
5027.94	*Fe*	1	0				0	0		0–1				
5029.66	...	0000	00–0					0		00				
5036.64	*Ti*	2	3				3	3		3				
5038.58	*Ti*	2	3–4				3–4	3–4		3				
5039.43 }	*Fe*	3	} 4				4	4		4				Winged
.54 }	*Ni*	00												
5040.14	*Ti*	3	4				3–4	4		4				
5040.79	*Ti*	00	1				0–1	1		1				
5043.76	*Ti*	00	0–1				n. c.	0–1		1				
5045.58	*Ti*	00	0–1				0–1	0		1				
5048.61	*Fe*	3	2–3				2	2		n. c.				
5052.08	*Cr*	0	0–1				0–1	0–1		0–1				
5053.06	*Ti*	0	1				1	0–1		1				
5058.67	*Fe*	00	0					0		0				
5060.26	*Fe*	3	3–4		n. c.	4	n. c.	4		4	n. c.			
5062.28	*Ti*	0	1		0–1	1	0–1	1		1	0–1			

TABLE I—*Continued*

Rowland: Wave-Length	Rowland: Element	Rowland: Solar Intensity	Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
5064.84	*Ti*	3	4		3–4	3–4	4	4		4	4			
5066.08	*Cr*	000	1–2		1	1–2	1	2		2	2			Blend
.17	*Ti*	000												
5066.91	...	00	0		0	0	0–1	0		0				
5068.48	*Cr, Ti*	0000	0				00–0	0		0				
5071.67	*Ti*	0	1		1	1	1	1		1–2	1			
5073.11	*Cr*	1	1–2		n. c.	1–2	1–2	2		2	n. c.			
5073.92	...	000	0				0	0		00–0				
5080.71	*Ni*	4	3–4		3–4	n. c.	3	3		n. c.	3			Hazy
5082.53	*Ni*	2	1		1	1	1	0		1	0–1			
5083.88	...	000	00			0	00	00		00				
5085.34	*Ti*	0000	00				00	00						
5086.95	...	000	0		0–1	0	0–1	0		00				
5087.24	*Ti*	0	2		1–2	2	2	2		1–2	2			
5092.28	...	0000	0				0	0						Probable blend
.48	...	00												
5094.20	...	000 N	0			00–0		0						
5110.57	*Fe*	5	5–6		n. c.	6	5–6	6		6	n. c.			Hazy
5113.30	*Cr*	00	0		n. c.	0	0	0		0–1	0			
5113.62	*Ti*	0	1		1	1	1	1		1–2	1			
5115.96	*Fe*	0	00–0			00	00	0		00				
5120.59	*Ti*	0	0–1		0–1	1	1	1		n. c.	n. c.			
5120.80	...	000	00–0			0	00–0			00				
5121.73	*Ni*	0	1–2		1–2	1	1	1		1–2	2			Thinned on violet edge
.82	*Fe*	2												
5122.97	*Co*	000	0–1		0	0–1	0	1		0–1				
5123.64	*Cr*	000	00		n. c.	00	00	00		00–0	00–0			
5127.86	...	00	0		n. c.	0	0	0		1	0			
5129.80	*Fe*	1	00		00	000	00	00		0	000			

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5131.64	*Fe*	2	1–2		n. c.	1	1	n. c.		n. c.	1			
5132.84	. . .	00	000		n. c.	n. c.	000	0000		0000	000			
5136.27	*Fe*	00	1		1	1	1	1		0–1	0		0–1	
5137.25	*Ni*	3	3–4		4	3–4	4	n. c.		n. c.	4		n. c.	
5139.43	*Fe*	4	9		10	8	10	8		10	9		10	Winged
.64	*Fe*	4												Hazy to violet
5141.92	*Fe*	3	3–4		4	4	n. c.	n. c.		n. c.	n. c.		4	Hazy
5144.85	*Cr, C*	00	1				1	1					0–1	
5147.65	*Ti*	0	2		1–2	1–2	1–2	2		2	2		2	
5148.41	*Fe*	3	3–4		n. c.	3–4	n. c.	3–4		n. c.	4		4	
5152.09	*Fe*	3	4		4	4	4	4		n. c.	4		4	Fringe on violet edge
5152.36	*Ti*	0	1		0–1	1	1	1		1–2	1		1	
5156.82	*C*, —	00	1				0–1	1						
5159.23	*Fe*	2	1		1	1	1–2	1–2		1–2	1		1–2	
5164.72	*Fe?*	1	0–1		0	0–1	0–1	0–1		n. c.	0		0	Bright space at 5163.7
5166.45	*Cr, Fe*	3	3–4		3–4	3–4	3–4	4		4	4		n. c.	
5169.07	*Fe*	3	5		5	5	5	5		6	5		6	Weak on red edge
.22	*Fe*	4												
5176.95	*V*	000	0		0	0	0	0–1		0	00–0		0	
5177.41	*Fe*	0	1–2		1–2	1–2	1	1		1–2	1		1–2	Hazy
.58	*Co*	00												
5187.62	. . .	000	0		0	0	0	00–0		00	0		0	
5188.08	*Fe*	1	0–1		n. c.	0–1	0–1	0–1		n. c.	0–1		0–1	
5188.86	*Ti*	2	6		6	6	6	6		6	n. c.		6	Hazy toward violet
89.02	*Ca*	3												
5191.63	*Fe*	4	5	5–6	5	5	5	5		5	5		n. c.	Hazy
5192.16	*Cr*	00	0		0	0	00	0		0–1			0	
5195.11	*Fe*	4	5	5	5	5	5	5		n. c.	5		n. c.	Winged
5196.23	*Fe*	1	2	2	2	2	n. c.	n. c.		2	2		2	Fringe on violet edge

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5196.61	*Cr*	0	1		1	1	0–1	0–1		1–2			2	Widening due to *Mn* component probably
.74	*Mn*	00												
5197.33	*Ni, Mn*	00	0–1					0–1					0–1	
5197.74	...	2	0–1			0	0	0–1		1			1	
5198.89	*Fe*	3	4	5	4–5	4	4	4		4	4		4–5	
5200.36	*Cr*	00	00–0	0	n. c.	n. c.	n. c.	0		00–0	00–0		00–0	
5201.26	*Ti*	000	0	0	0	0–1	0	0		0	0		0	
5204.68	*Cr*	3	10	10	10	9	10			10	10		10	Fringe on violet edge
.77	*Fe*	5												
5206.22	*Cr-Ti*	5	6	7	7	6	5–6			6	6		6	
5208.60	*Cr*	5	6	5	7	6	6			6	5		6	
5210.56	*Ti*	3	5	4	5	5	5			5	5		5	Hazy
5212.86	...	000 Nd?	0							0			0	
5214.29	*Cr*	00	0		0–1	0	0			0			0	
5214.78	...	00	0		0–1	0	0			0			0	
5218.08	*Fe*	0	0–1	1	0–1	0	n. c.			n. c.	0–1		1	
5221.93	*Cr*	0	1	1	0–1	0–1	1			0–1	1		1	
5222.56	*Cr*	00	00–0	00	0	00–0	00–0			00–0	n. c.		00–0	
5222.85	*Ti, Cr*	00	0	00	0–1	0	0			0	0		0	
5223.79	...	000	0	0	0	0	00			0	0		0	
5224.24	*Cr*	000 N	00–0							00–0			00–0	
5224.47	*Ti*	0	1	1	1	1	1			1	1		1	
5225.10	*Cr*	0	1–2	1	2	1–2	1			2			1–2	
.20	*Cr, Ti, Fe*	00												
5225.70	*Fe*	2	3	3	3	3	2–3			3–4	4		3	
5227.04	*Fe-Cr*	3	4	4	4	4	4			4	3		3–4	
5230.38	*Co, Cr*	00	1	1	1	1	0–1			1	1		0–1	
5233.12	*Fe*	7	8	8	8	8	7–8			n. c.	8		8	Winged
5234.02	...	0000	00		00	00				00			0	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5234.38	...	000	00		00	000				00			00	
5234.79	...	2	1	1	n. c.	1	0–1			1	1		1	
5235.35	*Co*	000	00–0	0	00	00	00			00	00		0	
5237.49	*Cr?*	1	0–1	0–1	0–1	0–1	0–1			0–1	0		n. c.	
5238.74	*Ti*	000 N	1	0–1	1–2	1	1			1–2	1		1–2	
5239.14	*Cr*	00	0	0	0	0	0			0–1	0		0–1	
5241.04	...	000	00	00–0	00	00–0	00–0			00	00		n. c.	
5243.53	*Cr*	00	0	0	0	0	0			0			0	
5246.73	...	0000	00–0	0	0	00	00			00–0			00–0	
5247.23	*Fe*	2	1–2	1–2	1–2	n. c.	1–2			n. c.	2		2	
5247.74	*Cr*	2	2–3	2–3	2–3	n. c.	2–3			3	2–3		3	
5249.28	*Fe*	00	0	n. c.	0	0	0			0	0		0	
5250.38	*Fe*	2	3	3	3	2–3	2–3			3	3		3	
5251.67	...	...	00–0	00	0	00	00–0			00			0	Rowland gives no line here
5252.15	*Fe*	0	2	2	2	1–2	2			2	2		3	
.28	*Ti*	000												
5253.20	...	00	0	0	0	00–0	00			0–1	0		0	
5255.12	*Fe*	3	4	4	5	4	4			4–5	4		4	
5255.49	*Mn*	0	0–1	0–1	0–1	n. c.	0–1			n. c.	0–1		0–1	
5255.91	...	000	1	1	1–2	1	1–2			0–1	1		1	
.97	*Ti*	0000												
5260.14	...	000	0	0	0	0–1	00–0			00				
5260.56	*Ca*	0	1	1	1	1	1			1–2	1		1–2	
5264.33	*Cr*	4	9	8	9	8	9			10	9		9	
.42	*Ca*	3												
5264.98	...	0	00	00–0	n. c.	00–0	000			00	00		00	
5266.14	*Ti*	0	0–1	n. c.	1	0–1	0–1			0–1	n. c.		0–1	
5269.72	*Fe*	8 d?	9	10	8	9	10			10	8		9	Winged
5275.15	...	0	00	n. c.	00	00	000			00	00		n. c.	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5275.34 }	*Cr*	00	} 2–3	2	2–3	2–3	2			2	2–3		2–3	
.45 }	...	1												
5275.93	*Cr*	1	2	1–2	2	2	2			2	1–2		2–3	Hazy
5280.54	*Fe*	1	1–2	1–2	1–2	1–2	n. c.			1–2	n. c.		1–2	
5282.58	*Ti*	00	1	0–1	1	1	1			1	1		1	
5284.60	*Fe, Ti*	00	0		0	0	0			00–0			00–0	
5284.79	...	00	00–0		00					00–0			0	
5285.82	...	000	00		0	00–0	00			00			00	
5287.35	*Cr*	000	0	0	0–1	0–1	0			0				
5289.45	...	000	00–0	00	0	0	00			00–0				
5290.98	...	000	00			0	00			00				
5295.96	Awv ?	00	1	0–1		1–2	1			1	1		0–1	
5296.87	*Cr*	3	4	4		4–5	4–5			4	3–4		4	
5297.41	*Cr, Ti*	000	00–0	00		0	00			00–0	00		0	
5298.46	*Cr*	4	6	5–6		6	6			6	5		6	Hazy
5300.15	...	00	0–1	0		1	0–1			0	0		1	
5300.93	*Cr*	2	3	3		3	3			3	3		3	
5301.22	*Co*	00	00–0	n. c.		0	0			n. c.	00–0		0	
5302.48	*Fe*	5	5–6	6		6	6			n. c.	6		n. c.	
5304.36	*Cr*	0	1	1		1	0–1			0–1			1	
5307.54	*Fe*	3	4	3–4		4	4			4	3–4		4	
5313.03	*Cr*	0	0–1	1		0–1	n. c.			n. c.	0–1		0–1	
5324.37	*Fe*	7	7	n. c.		n. c.	8			n. c.	n. c.		n. c.	Winged
5329.33	*Cr*	3	4	3–4		4	3–4		4	3–4	4		4	
5329.98	*Cr*	0	0–1	n. c.		n. c.	0–1		0–1	n. c.	0–1		0–1	
5331.64	*Co*	00d	0	0–1		0	00–0		0	0	0	0	1	
5335.05	*Co*	1	0	0		0–1	0		0	0	00	0–1	0	
5337.91	...	0	00						000	00		00		
5338.52	...	00 N	0–1	0		0–1	1		0	0		0	0–1	

TABLE I—*Continued*

Rowland: Wave-Length	Rowland: Element	Rowland: Solar Intensity	Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
5341.21	*Fe*	7	10	10		10	10		10	10		10	10	Weak on red edge
.34	*Mn*	1												
5343.15	...	0000	00	00		00				00		000		
5344.94	*Cr*	00	00–0	0		00–0			0	0		n. c.		
5345.99	*Cr*	5	7	6		7			6	7	7		7	Winged
5348.51	*Cr*	4	6	6		7			6	6	6	6	6	Winged
5349.65	*Ca*	4	4–5	n. c.		5			n. c.	n. c.	5	5	n. c.	
5351.26	*Ti*	00	1	1		0–1			0	1	1	1	1	
5356.27	...	000	00	00–0		00			00	00–0		000–00	00	
5366.83	...	000	0	0		0			00–0	0	0	0–1	1	
5369.78	*Co-Ti*	1	2	2–3		2–3	2		2	1–2	2	2	3	
5371.66	*Cr ?*	4	10	10		10	n. c.		10	10	10	10	10	Winged
.73	*Fe*	3												
5373.90	*Fe, Cr*	2	2–3	n. c.		2–3	n. c.		2–3	2–3	2–3	n. c.	2–3	
5384.83	...	000	00–0	00		00	00–0			00		00–0	00–0	
5387.16	*Fe, Cr*	0	1	0–1		1	1		1	0–1	1	1	1	
5387.77	*Cr*	00	1	0–1		1	1		0–1	0	0	1–2	1	
5389.37	...	000	0–1	0		0	0–1		0	0	0	1	1–2	
5390.05	...	00	0	0		0	0		n. c.	0	0	1	0–1	
5393.38	*Fe*	5	5–6	n. c.		5–6	6		n. c.	6	6	n. c.	n. c.	
5394.84	*Mn*	1	4	3		4	4		4	4	3	4	4	Diffuse
.91	*Mn*	1												
5396.78	*Ni*	000 N	1	1		1	0		0	1	0–1	1–2	1–2	
5397.34	*Fe*	7 d?	9	8		9	8		8	10	8	10	9	Winged
5399.68	*Mn*	1 Nd?	1–2	2		1–2	1–2		1–2	1–2	2	1–2	1–2	Hazy
5401.47	...	0	1	0–1		0–1	1		1	1	1	1	1	
5404.36	*Fe*	5	5–6	n. c.		n. c.	6		6	n. c.	6	n. c.	6	
5405.55	...	1	1–2	2		1–2	1–2		n. c.	1–2		1–2	n. c.	
5405.99	*Fe*	6	8	8		8	8		7	8	7	8	8	Winged

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5407.59 .69	*Mn* *Mn*	o o	2–3	2		2–3	2–3		2	2–3	2	2–3	2–3	Diffuse
5409.02	...	ooo	o	o			o		oo	oo	oo–o	1	1	
5410.00	*Cr*	4	6	5		6	6		n. c.	6	5–6	7	7	Fringe on violet edge due to *Ti* line
5413.00	*Mn*	oo	oo–o	o		n. c.	n. c.		oo–o	oo–o	o	o	oo–o	
5413.89	*Mn*	oo N	o	o		oo–o	oo–o		n. c.	o	o	o–1	o	
5419.42	A ?	oooo	oo	ooo		oo–o	oo–o					o	oo	
5420.51 .61	*Mn* *Mn*	o N o N	3	2–3		2	3		3	3	2–3	3	3	Rowland's intensities poor
5425.46	...	1	o–1	o–1		o–1	n. c.		o–1	o	o–1	n. c.	n. c.	
5426.47	...	oo	2	2		2	2–3		1–2	1–2	2	2	2	
5429.35	...	oo	oo–o	o		n. c.	oo–o		oo–o	o	oo–o	o	oo–o	
5429.91	*Fe*	6	8	7		8	7		8	8	7–8	8	n. c.	Hazy
5432.75	*Mn*	1	3	2–3		2–3	3		2–3	2–3	3	3	3	
5436.80	*Fe*	1	2	2		2	1–2		1–2	2	1–2	2	2	
5438.51	...	ooo	o	oo–o		oo	o		o	o	o	o–1	oo–o	
5440.86	...	ooo	oo–o	oo		oo	oo–o			oo		o	oo–o	
5442.63	*Cr*	oo	o	o		o	o		o	n. c.	o	1	o	
5447.13	*Fe*	6	8	8		8	8		8	7	8	8	n. c.	Winged
5448.58	...	oo	oo–o	o		o	oo		oo–o	oo–o		oo–o	n. c.	
5453.86	...	ooo	oo–o	oo		oo	oo–o		o	o	oo	o–1	o	
5457.64 .70	*Mn* *Mn*	ooo ooo	o	o		o	oo–o		o	oo–o	o	o	oo	Hazy
5460.72	...	oo	2–3	2		2–3	2–3		2	2	2	3	3	
5461.76	...	o	1	1		1–2	1		1	o–1	o–1	1	o–1	
5464.18	*Cr*	ooo	oo	oo		o	oo		oo	oo	oo	oo	oo–o	
5465.94	...	...	o									o	oo–o	Rowland gives no line here
5470.80 .88	*Mn* *Mn*	o o	2–3	2		2	2–3	2–3	3	3	2	3	3	Hazy

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5471.41	*Ti*	000	1–2	1		1–2	1–2	1–2	1–2	1–2	1	1–2	1–2	
5473.37	...	00	00–0	00–0		0	00–0	0	n. c.	0	0	00–1	n. c.	
5474.44	*Ti?*	00	0	0		0	0	0	0	0	0	1	0–1	
5474.96	...	0000 N	00–0					0			00–0	00–0	00–0	
5477.90	*Ti*	00	1–2	1		1–2	1–2	1–2	1	1	1	2	1–2	
5482.08	...	00	1–2	1		1–2	1–2	1–2	1	1	1	2	1	
5482.47	...	000 N	00–0									00	0	
5483.57	*Co*	1 d?	1–2	1–2		1–2	1–2	1–2	1–2	1–2		1–2	n. c.	
5484.85	...	000	00–0	00		00	00–0	0		00–0	0	0	00–0	
5485.76	...	000	0									00–0	0	
5488.37	...	00 Nd?	1	0–1		1	0–1	1	1	1	1	1	1	
5490.37	*Ti*	0	3	3		2	3	3	3	3	3	3	3	
5490.90 }	...	0	} 1–2	1		1–2	1–2	1–2	0–1	1	1	1–2	2	Widening due to red com ponent mainly
91.04 }	...	000												
5493.71	*Fe*	1	1–2	n. c.		1–2	1–2	1–2	1–2	1–2	1–2	1–2	1–2	
5494.68	*Fe*	0	0–1	n. c.			0–1	0–1	0–1	1	1	0–1	0–1	
5495.10	*Ni*	00	0	0			00–0	00–0	0	00–0	0	0	0	
5495.66	...	...	00–0					0	00			00–0	00	Rowland gives no line here
5496.12	...	0000	00									00	00	
5497.74	*Fe*	5	6	6		n. c.	n. c.	n. c.	7	8	6	n. c.	7	
5504.12	*Ti*	0	1	1		1	1	1	1	1	1–2	1	1	
5506.10	*Mn*	1	2	1–2		1–2	1–2	2	2	2	2	1–2	2	
5507.00	*Fe*	5	7	6		6	6	7	7	7	6–7	7	7	Winged
5512.01	...	00	0	0		0	0	0	0	00–0	0	1	0	
5512.74	*Ti*	2	3	3		3	3	3	3	3	3	3	3	
5514.56	*Ti*	2	3	2–3		3	2–3	3	3	3	2–3	3	3	
5514.75	*Ti*	2	2–3	2–3		3	2–3	2–3	2–3	2–3	2–3	3–4	2–3	
5516.95 }	*Mn*	0	} 2	1–2		1–2	1–2	1–2	2	2	2	2–3	2	Diffuse
17.03 }	*Mn*	0												

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5520.73	...	00N	1	1		0–1	1	1	0	0		1	2	
5527.80	...	000d	00–0									00–0	0	
5529.38	*Fe*	00	0									0	0	
5531.00	*Ti*	00N	0–1	1		0	0–1	1	0–1	1	0	0–1	0–1	
5535.06	*Fe*	2	1						1–2	1		1	1	
5535.64	*Fe*	2	3–4	3–4		.	4	3–4	3	3		4	4	
.78	...	0												
5537.93	*Mn*	00	2	2	2	1–2	1–2	1	1–2	2	2	2	2	Diffuse
38.02	*Mn*	00												
5538.74	*Fe*	1	1–2	1–2	n. c.	1	1–2	1–2	1–2	2	1	2	1–2	Rowland's intensity poor
5546.73	*Fe*	2	2–3	2–3	2–3	2–3	2–3	2–3	2–3	2–3	n. c.	n. c.	n. c.	
5547.22	*Fe, V*	1	1–2	2	2	1–2	2	2	1–2	1–2	1–2	1–2	1–2	
5555.86	...	000	00–0		00			0	0	00		00	00–0	
.95	...	0000												
5565.70	*Ti*	00	2	2	2	1–2	1–2	2	1–2	1–2	1–2	2	2	
5573.76	...	0000	00	00	00	00	00	00	00			00	00–0	
5579.57	...	000	00–0		0	0	00	00	00	0		00	00–0	
5582.20	*Ca*	4	5	5	5	4–5	5	n. c.	n. c.	n. c.	n. c.	6	5	Winged
5583.19	...	000	00		00–0	00		00				00	00–0	
5584.73	...	000	00	00–0	0	00	n. c.	00	00	00–0	n. c.	00	00	
5586.99	*Fe*	7	8	8	8	8	8	8	9	9	8	8	8	Winged
5588.99	*Ca*	6	7–8	7	7	7–8	8	8	7	7	7	8	8	
5590.34	*Ca*	3	3–4	4	4	4	4	4	n. c.	n. c.	n. c.	n. c.	4	
5590.93	*Ti*	000	00–0		0	00–0	00–0	00	00–0	0		n. c.	00	
91.04	*Ti*	000												
5594.69	*Ca*	4	5	5–6	4–5	5	n. c.	5	5	5	5	5	5	Winged
5598.71	*Ca*	4	5	5	5	5	5	5	5	6	5	6	5	Hazy
5605.17	...	000	0	0	0	0	00	0	0	00–0		1	0	
5619.82	...	0	0–1	0–1	0–1	0–1	0–1	0–1	0–1	n. c.		n. c.	0–1	
5625.10	...	000	0	0	0	00	00	0–1		0		0	0–1	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5626.26	...	...	1	1	1	0–1	1	1–2		0		1	1	Rowland gives no line here
5627.86	*V*	00	2–3	2	3	1–2	2–3	2–3		2–3	2–3	3	3	
5628.87	*Cr*	00	0–1	0–1	0–1	0	1	0–1		0–1		1	1	
5630.31	...	000	00–0									00–0	0	
5644.26 }	...	00	} 2–3	2	2–3	2	2	3		2	2	3	3	
.37 }	*Ti*	0												
5645.83	*Si*	1	00–0	0	0	00	0	0			0	000	00	
5646.04	...	00	1	1	1	0–1	1	1–2		0–1	1	1–2	1–2	
5647.46	*Ti*	00	0–1	0–1	1	0	0	0		0–1	0–1	0	0–1	
5648.80	*Ti*	00	2	2	2	1–2	1–2	2	1–2	1–2	1–2	2	2	
5651.69	*Fe*	0	0–1	0–1	1	n. c.	0–1	n. c.	n. c.	0–1	1	n. c.	1	
5654.09	*Fe*	1	1–2	1–2	n. c.	n. c.	n. c.	n. c.	1–2	1–2	1–2	1–2	1–2	
5657.67	...	000	1	1	1	1	1	1–2	0–1	0–1	1	1–2	1–2	
5658.10	*Y*, —	2	1–2	n. c.	1–2	1–2	n. c.	n. c.	n. c.	1–2	1–2	1–2	1–2	
5662.37	*Ti*	0	1–2	1–2	1–2	1–2	1–2	1–2	1–2	1–2	1–2	2	2	
5663.16	*Ti, Fe, Y*	1	1–2	1–2	2	2	1–2	1–2	1–2	1–2	1–2	1–2	2	
5664.80	...	000	0			0	00	0		0		0	0	
5665.78	*Si*	1N	0					0				00–0	0	
5668.59	*V*	000	1	1	1–2	0–1	0–1	1–2	0–1	0–1	1–2	1	2	
5669.26	...	1	0	0	0	0	0	0	0–1	0–1	0	0	0	
5671.07	*V*	0	3	3	3	2–3	2–3	2–3	2–3	3	3	3–4	3–4	
5672.05	*Sc*	0	2	2	2	2	2	2	1–2	2	2	2–3	2	
5675.65	*Ti*	2N	2–3	3	2–3	n. c.	2–3	3	3	2–3	2–3	2–3	3	
5680.15	...	000	0–1	0	0	0	0–1	1	00–0	0	1	0	0–1	
5682.87	*Na*	5	7	7	7	7	7	7	6	6	6	8	6	
5684.71	*Si*	3	1–2	2	2	2	2	1–2	1–2	1–2	2	0	1	
5687.06	...	000	1–2	1–2	1–2	1	1–2	2	1	1	2	2	1–2	
5688.44	*Na*	6	7	7	8	n. c.	8	6	n. c.	n. c.	7	8	7	Winged
5689.69 }	*Ti*	0	} 2	2	2	1–2	2	2	2	2	2	2	2–3	
.81 }	A?	0												

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 40	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5690.65	*Si*	3	2–3	2	2–3	2	n. c.	n. c.	n. c.	2	2	2	n. c.	
5694.96	*Cr*	0	1	1	0–1	1	0–1	n. c.	0–1	1	1	1	0–1	
5698.56	*Fe, Cr*	1	2	2	2	2	1–2	2	2	1–2	2	1–2	2	
5698.75	*V*	1	3–4	4	4	3	3	3	3	3	3–4	3–4	3	
5700.51	*Cu?*	00	2–3	2–3	3	2–3	2	2–3	2–3	2	2	2–3	3	
5701.32	*Si*	0N	00	00	00	00–0	00	00	00	00	000	00	00	
5702.54	*Cr*	0	1	1–2	1–2	0–1	1	0–1	1	1	2	1	1	
5702.88	*Ti*	000	0–1	1	1	0	1	0–1	0	0–1	1	0–1	1	
5703.80	*V*	1	3	3	3	3	2–3	3	2–3	3	3	3	3–4	
5707.20	*V*	0	3	3	3	3	3	3	3	3	3	3	3–4	
.26	*Fe*	1												
5708.62	*Si*	3	1–2	2	2	2	1–2	2	2	2	1	1	1	
5709.60	*Fe*	5	7	6	7	7	7	7	8	8	6	7	7	
5712.10	*Fe*	3	5	4	5	5	5	5	4	4	6	6	5	Hazy
5713.00	*Cr*	0	1–2	1	1–2	1	1–2	1–2	1–2	2	2	1	1–2	
5714.12	...	000	00–0	0	00	00	00	0	0	0	0	0	0	
5716.67	*Ti*	00	2	1–2	2	2	2	2	1	1	2	2	2	
5717.92	...	000	00		00			00	00		00–0	00	00	
5720.67	*Ti*, A	0	1–2	1	1–2	1	1–2	2	1	1	1	1	2	
5727.27	*Ti-V*	2	3–4	3	3–4	3–4	3	3	3–4	3	3–4	4	4	
5727.87	*Cr?*	00	3	3	3	3–4	3	3	3	3	3–4	3–4	4	
5731.44	...	00	4	4	4	4	4	4	3	2–3	4	4	4	
5735.79	A	0	1	0–1	0–1			1–2	1	1		1	1–2	
.92	...	00												
5737.29	...	0	3–4	4	4	3	3–4	3	3	3	3	4	4	
5739.70	...	0	2	1–2	1–2	2	1–2	1–2	2	1–2	2	2–3	2	
5740.20	...	0	1–2	1	2	0–1	1–2	1	1–2	1	2	1–2	1–2	
5741.43	A?	000	00–0	0		00		00		0		00		
5743.64	...	00	3	3	3	3	3	3	2–3	2	4	4	3	
5744.15	...	00	0–1	1						0	0–1	0–1	0	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5748.18	*Fe*	2	2–3	2–3	2–3	n. c.	n. c.	2–3	2–3	2–3	n. c.	2–3	n. c.	
5748.58	*Ni*	2	2–3	3	2–3	2–3	2–3	2–3	2–3	2–3	n. c.	3	2–3	
5754.88	*Ni*	5	5–6	5–6	n. c.	n. c.	6	5–6	n. c.	6	n. c.	7	6	Hazy
5760.57	*Fe*	1	1–2	2	1–2	1–2	1–2	1–2	1–2	1–2	2	1–2	1–2	
5762.48	*Ti*	oooNd?	2–3	2	2	3	2–3	3	2–3	2	2	2–3	2	Widening due mainly to *Ti* line
.64	*Fe*	1												
5766.55	*Ti*	0	1–2	2	2	2	1–2	1–2	1–2	1–2	2	2	1–2	
5771.82	. . .	00	0	n. c.	0	0	0	0–1	0	0	0	0		
5772.36	*Si*	3	1–2				1–2	2	2	2		0–1	1–2	
5774.25	*Ti*, A	0	1–2	2	1–2	1–2	1–2	1	1	1	2	1–2	1–2	
5776.96	A, —	000	0–1		0	0	0	0			1	1	0–1	
5778.68	*Fe*	1	2	2	2	1–2	1–2	2	2	2	2	2	1–2	
5780.82	*Fe*	2	2–3	3	2–3	3	2–3	n. c.	3	n. c.		n. c.	n. c.	
5781.02	*Fe*	0	1	1	1	1	1	1	1	1	1	1	1	
.13	*Cr, Ti*	00												
5781.40	*Cr*	0	2	2–3	2	2	1–2	1–2	1–2	1–2	3	1–2	2	
5781.97	*Cr*	0	1	1	1	1	1	1	1	1	2	0–1	1	
5783.29	*Cr*	2	3–4	4	4	4	3–4	3–4	3	3	4	3	3	Hazy
5784.08	*Cr*	3	4	5	4	5	n. c.	n. c.	3–4	4	4	4	3–4	
5785.19	*Cr*	2	2–3	3	3	3	2–3	n. c.	n. c.	n. c.	3	3	3	
5785.95	*Cr*	1	2–3	3	2–3	3–4	3	2–3	2	2	2	2	3	
5786.19	*Ti, Cr*	oN	1–2	2	1–2	2	1–2	2	1	1	2	1–2	1	
5787.24	*Cr*	00	0	0	0	0	0–1	0	0–1	0		0	1	
5798.08	. . .	3	2–3	2	2	2	2–3	n. c.	2	2	2–3	2–3		
5804.48	*Ti*	0	1–2	1–2	1	0–1	1–2	1–2	1–2	1–2	1–2	1–2	1–2	
5805.99	*La*	0	0–1	n. c.	0–1	0–1	n. c.	0–1	0–1	0–1	1	n. c.		
5823.91	. . .	00	1–2	2	1–2	2	2	1–2		1	1	2		
5828.10	. . .	0	1	1	1	1	1–2	1	1	1	1			
5847.22	*Ni*	1	2	2	2	3	3	2–3	1–2	1–2	3			
5853.54	. . .	000	0	00	0	0			1	0	0			

character of these missing lines is very different in the two cases. Those absent from our list are for the greater part lines of medium or considerable intensity which appear in Mitchell's list as only slightly affected. In the case of such lines it is always difficult to be certain of a slight variation in intensity, and, while most of these lines have been observed by us, the mean variation has been too small for them to be included in the table. On the other hand, the lines present in our list and not in that of Mitchell are for the most part coincident with very faint lines in the solar spectrum, and would be classed as "band-lines" if we made use of that term.

Although the list of lines which we have given is intended rather to show the possibilities of the photographic method than to serve as a definitive table, it will not be out of place to give a brief analysis of them with especial reference to the elements to which they belong. An inspection of the table gives the following results:

TABLE II

Element	No. of Lines Affected	Mean Change of Intensity	No. of Lines Weakened
Fe	60	0.5	10
Ti	48	1.2	..
Cr	43	0.9	1
Mn	13	1.1	..
Ni	9	0.3	2
Ca	7	0.9	..
Si	7	—1.1	7
Co	6	0.3	1

Lines assigned to two or more elements	25
Blends	20
Unknown	94
Water vapor (all marked "?") by Rowland	3
Sodium	2
Sc, La, Cu, each	1

In forming the third column of the table, which gives the mean change of intensity on Rowland's scale, care has been used in combining results for lines above 1 and below 1 in intensity, the values of the intervals being by no means the same in the two cases. For example, the change in intensity between 1 and 2 is not at all the same as between 00 and 0. A considerable number of observations

was made in order to eliminate difficulty from this cause, and the results cannot be much in error so far as this source is concerned.

These observations strongly confirm Mitchell's conclusion that lines due to water-vapor are not affected in the spot spectrum. But three lines in the list are assigned by Rowland to water-vapor alone, and in the case of each of these the identification is marked doubtful.

The fact that only a little more than one-fourth of the lines in the table are "unknown" is decidedly opposed to Lockyer's view that at the period of sun-spot maximum the lines due to known elements are replaced by unknown lines. Even of this fourth a considerable proportion consists of such faint lines that their identification by Rowland would be improbable, since in the case of lines of intensity 00 on his scale an identification is much more the exception than the rule, and since the probability grows less with decreasing intensity. The evidence afforded by the iron lines is also opposed to Lockyer's conclusion. More than one-sixth of the total number of lines affected is due to that element alone, and it also enters largely into the composite and blended lines. It seems to us probable, as Cortie has suggested, that changes in the behavior of the iron lines may depend upon the character of the spots in which they occur, but at present we have by no means sufficient evidence to speak definitely on this point.

In a recent paper,[1] discussing his observations of the sun-spot spectrum in the region C to D, Fowler draws the conclusion that in the case of elements which are represented in the Sun by comparatively faint lines, such as titanium, vanadium, and chromium, the lines in the spot are strengthened in proportion to their intensities in the Sun. Our results do not support this conclusion. In the case of titanium, which is the element Fowler discusses in detail, we have, for example, in the lines λ 5566, λ 5649, and λ 5717 instances of lines strengthened from 00 to 2 on Rowland's scale. On the other hand, the stronger lines λ 5023, λ 5515, and λ 5676 are only very slightly affected, rising from 2 to 2–3 on the same scale. Perhaps an even more striking case is that of the line λ 5490, which rises from a solar intensity of 0 to 3 in the spot. This is a value that is surpassed

[1] *Monthly Notices*, **65**, 205–218, 1905.

by very few lines with a solar intensity as great as 2. Fowler remarks that "in photographs, at least, a general strengthening of all the lines belonging to an element produces a more obvious effect on the weaker lines than on the strong ones, though all may be intensified in the same ratio." This may have some effect in the case of elements with such strong lines that it is difficult to find lines in the adjoining solar spectrum of sufficient intensity for comparison purposes. In the case of titanium, however, even the strongest lines in the region under discussion are of very moderate intensity, and plenty of suitable comparison lines are available, so that it is difficult to see how much error can arise from the source which Fowler mentions.

In concluding this preliminary discussion of our results, attention should be called to the remarkable behavior of silicon, all the lines of which in this region of the spectrum, 7 in number, are much weakened. Mitchell finds a similar result for 5 lines. In view of the importance attaching to the carbon group of elements in the Sun, this result is of especial interest.

"BANDS" IN THE SPECTRA OF SUN-SPOTS

In describing the spectrum of a spot observed from April 11 to April 13, 1869, Secchi speaks of several groups of very fine lines which lie close together in the general spectrum of the Sun, but appear in spots as diffuse and nebulous lines:

> Dans la région du vert, il y en a un très-grand nombre qui deviennent très-noires dans les taches, tandis que sur le reste du disque on a beaucoup de peine à les distinguer. Ces systèmes ne paraissent cependant pas être des créations nouvelles tout à fait particulières aux taches; ils correspondent ordinairement à des raies très faibles indiquées par Kirchhoff; mais ces raies prennent dans les taches un développement extraordinaire, ce que constitue un phénomène bien tranché et complétement caractéristique.[1]

These observations, which describe very accurately the phenomena of spot bands, have received little or no mention in the literature of the subject.

In his Mount Sherman observations, Professor Young noticed between C and D in the spot spectrum some peculiar shadings terminated sharply by hard dark lines on the less refrangible side and fading out gradually in the other direction.[2] The Greenwich obser-

[1] *Le Soleil*, 2d ed., **1**, 288.

[2] *Nature*, **7**, December 12, 1872.

vations of spot "bands," which have been frequently cited, were made during the years 1880 to 1883. Many of the "bands" were only about one tenth-meter broad. On November 18, 1881, the "bands" "seemed to be composed of fine lines, but this could not be ascertained with certainty."[1] Father Cortie distinguishes three types of "bands." The first, "a certain fuzzy appearance surrounding the widened portions of the dark lines," is merely a special case of widening. The second results from increased general absorption in certain parts of the spectrum, while the third is "the appearance of real bands in the selective absorption due to a spot."[2] The lack of uniformity of the general absorption is precisely what gives rise, in our photographic observations, to the appearance of bands, and particularly to the "bands" observed at Greenwich. These are included by Father Cortie in his third class (bands proper), together with the bands observed by Professor Young at Mount Sherman. Father Cortie discusses in this paper his observations of two "bands" in the red, and remarks that "these bands or groups of lines were due to the spot alone, for no trace of them could be detected when the spot was removed from the slit, and they stand out most clearly and distinctly in the darkest part of the umbra." He concludes that bands of the third class "belong exclusively to sun-spot spectra" and are "altogether distinct from the ordinary widened or darkened or obliterated lines of such spectra." Vogel's observations of spot spectra, which may be found in the *Bothkamper Beobachtungen*,[3] include a number of bands, some of which were resolved into lines. More recent observations include those made photographically at the Yerkes Observatory in 1902,[4] and the visual results of Fowler and Mitchell, which are referred to below.

Before citing these, reference should be made to Young's well-known resolution of the dark background of the spot spectrum into fine lines:

> But the most striking result is that in certain regions the spectrum of the spot-nucleus, instead of appearing as a mere continuous shade, crossed here and there by markings dark and light, is resolved into a countless number of lines, exceedingly fine and closely packed, interrupted frequently between E and F

[1] *Greenwich Photographic and Spectroscopic Results*, 1881.

[2] *Monthly Notices*, **47**, 19, 1888.

[3] Unfortunately not yet in the library of the Solar Observatory.

[4] George E. Hale, "Solar Research at the Yerkes Observatory," *Astrophysical Journal*, **16**, 216, 1902.

(and occasionally below E) by lines as bright as the spectrum outside the spot. . . . . When seeing is at the best, and everything favorable, close attention enables one to trace nearly all these lines out beyond the spot and its penumbra. But they are so exceedingly faint on the Sun's general surface that usually they cannot be detected outside the spot spectrum. . . . . . Of course the resolution of the spot spectrum into lines tends to indicate that the absorption which darkens the center of the sun-spot is produced, not by granules of solid or liquid matter, but by matter in gaseous form.[1]

Dunér, in his memoir, *Recherches sur la Rotation du Soleil* (p. 12), describes his confirmation of Young's observations in the following words:

J'ai en effet vu le spectre des taches perdant tout-à-fait l'apparence d'une bande unie plus sombre que le reste du spectre solaire, laquelle il présente dans un spectroscope d'une dispersion moyenne, et montrant de très nombreuses raies sombres, projetées sur un fond du même éclat que le spectre général du disque solaire. Ces raies ne sont pas cependant uniformément réparties et à la même distance l'une de l'autre comme les lattes d'une grille. Au contraire, on voit avec une pleine sureté, surtout en portant son attention sur les espaces qui dans le spectre solaire sont vides de toutes raies tant soit peu fortes—je cite comme exemples les lacunes 5352 . . . . 5361 et 5287,5 . . . . 5292—qu'elles sont agroupées en doublets, triplets, etc., séparées par des interstices plus larges que ceux qui séparent les raies constituantes de ces groupes. Tous les interstices, autant que j'ai pu les voir, m'ont semblé être du même éclat que ceux qui se trouvent entre les groupes des raies dans le spectre solaire. En examinant très attentivement le spectre solaire, dans le prolongement d'un tel groupe dans le spectre des taches, il m'est quelquefois arrivé de découvrir un trait nébuleux excessivement faible. En un mot: tout ce que j'ai vu, me semble prouver qu'il n'y a pas de différence fondamentale entre le spectre solaire général et celui des taches. Il est au contraire fort probable, que celui-ci se forme, pour ainsi dire, par l'exagération des caractères essentiels de celui-là, les raies excessivement faibles, presque imperceptibles, devenant parfaitement visibles, et les raies qui, dans le spectre solaire ordinaire, sont fortes devenant élargies et renforcées.

In his recent paper, "Researches in the Sun-Spot Spectrum, Region F to *a*,"[2] Walter M. Mitchell, in speaking of the resolution of the spot spectrum into fine lines, remarks:

The lines are most closely crowded in the region $\lambda\lambda$ 5000–5160; in the lower

[1] A new line at λ 3884 ± 2, mentioned in this paper as exceedingly bright in the spectrum of a specially vigorous eruption of prominences, is very likely identical with the bright line at λ 3884.28 and λ 3884.67, in the "intermediate" and "abnormal" spectra described in our account of a remarkable disturbance of the reversing layer (*Astrophysical Journal*, **16**, 220, 1902).

[2] *Astrophysical Journal*, **22**, 4, 1905.

portions of the spectrum, particularly below D, the lines form groups rather than a uniform succession of lines as above the *b*'s. The writer doubts whether the greater part of these "band-lines" are lines ordinarily exceedingly faint in the photospheric spectrum, and brought into prominence by the vapors of the spot, but is inclined to the opinion that they are lines not present in the photospheric spectrum at all. . . . . Of course there are numerous "band-lines" that are fine and sharp, extending into and sometimes beyond the spectrum of the penumbra (long lines). These exceptional lines are undoubtedly faint lines in the ordinary spectrum.

Fowler observed two of the bands in the red described by Cortie (λ 6381.6 and λ 6389.0), and found them sharper on the red side, and not resolved into lines.[1] In the same region, however, Mitchell records seventeen groups of fine lines. Many of the bands observed by Maunder in the green were seen by Fowler, whose measures of their positions agree well with the positions determined by measurement of the photographs taken at the Yerkes Observatory. In his observations of the great sun-spot of February and March 1905, Fowler was able to observe the resolution of the continuous absorption band into lines, in spite of the comparatively small dispersion of his spectroscope.

The general appearance of the band was very similar to that of a complex banded spectrum, such as that of sulphur, in which the maxima or "heads" are not very pronounced. Under favorable conditions, Young and Dunér were able to trace the dark components of the spot band structure in the spectrum of the disk outside the spot, but this was not clearly seen in my observations.[2]

Fowler noticed, however, that the bright gaps which occur here and there among the crowded dark lines of the "spot bands," occupy spaces between nebulous lines of low intensity in Rowland's table.

It is accordingly not improbable that the absorbing vapor which is chiefly responsible for the darkness of a spot is thinly distributed over the general surface of the Sun, and may account for some of the very numerous faint lines of the Fraunhofer spectrum.[3]

As will be seen from the photographs reproduced in Plates IV and V, and also from the wave-lengths of the lines in the "spot-bands" given in Table III, our results completely bear out this inference. In discussing these results, the first question that arises is whether

[1] *Monthly Notices*, **65**, 217, 1905.

[2] *Ibid.*, p. 515.

[3] *Ibid.*, p. 516.

the lines in our photographs are to be regarded as identical with the fine lines observed visually by Young and Dunér. These lines were frequently seen visually by Mr. Hale in his observations of spot spectra at the Kenwood Observatory with a spectroscope not differing greatly in resolving power from the instruments employed by Young and Dunér, and subsequently by us both at the Yerkes Observatory. It may be said at once that our photographs do not show as complete a resolution of the fine lines as can be observed visually. Nevertheless, we have no doubt that the majority of the lines are shown photographically, and that the lack of more complete resolution simply arises from the fact that the linear dispersion is not great enough for the purpose. The numerous lines particularly noted by Dunér, in the above quotation from his paper, as lying in the blank regions of the solar spectrum at λ 5352–λ 5361 and λ 5287.5–λ 5292, are clearly shown in our negatives, though they may not appear in the reproductions accompanying this paper (Fig. 2, Plate IV). The best evidence, however, that the lines we have recorded represent the resolution of the "spot-bands," lies in the fact that the wave-lengths of these lines agree very closely with the wave-lengths of the very faint lines in Rowland's table. In spite of the observations of Young and Dunér, the question of the identification of the fine lines in spots with the faint lines in Rowland's table has remained unsettled, as is indicated by the fact that Mitchell expresses the opinion, in a quotation given above, that the spot lines are distinct from the faint solar lines. We have here a demonstration of one of the advantages of photography, which permits accurate measurements of the wave-lengths of such lines to be made, whereas these measurements would hardly be possible in the case of visual observations.

In spite of our identification of these fine lines of the "spot-bands" with the faint lines of the solar spectrum, we cannot subscribe to the opinion expressed by Dunér "that there is no fundamental difference between the general solar spectrum and that of the spots." If, in accordance with what appears to be his view (see the above quotation from his memoir), the spot spectrum is produced by a general increase in the intensity of the lines of the solar spectrum, no such differences in the relative intensities of the spot lines as are plainly shown in

PLATE IV

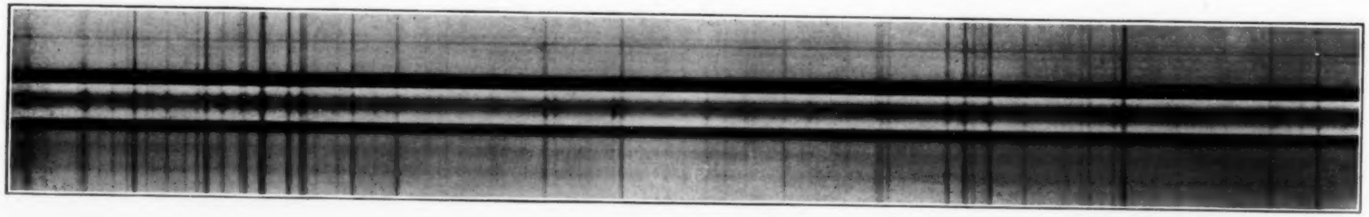


FIG. 1.—Region $\lambda 5695$–$\lambda 5775$

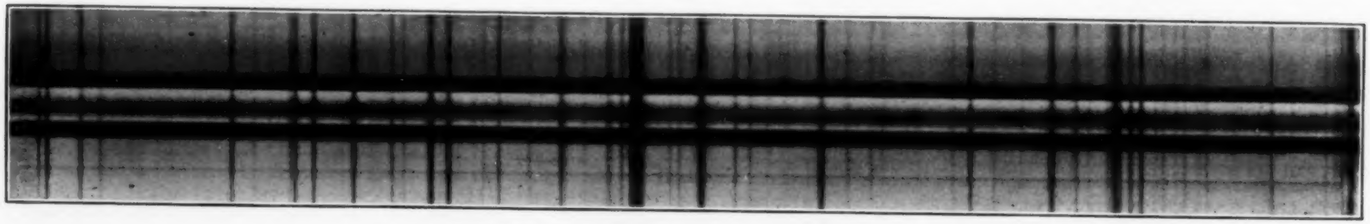


FIG. 2.—Region $\lambda 5285$–$\lambda 5365$

PLATE V

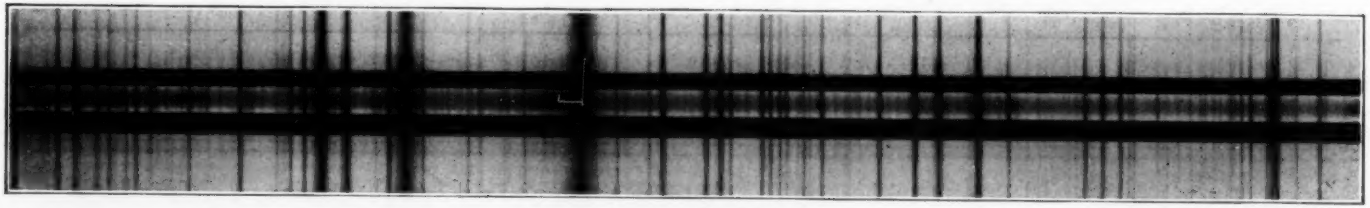


FIG. 1.—Region λ5150–λ5270

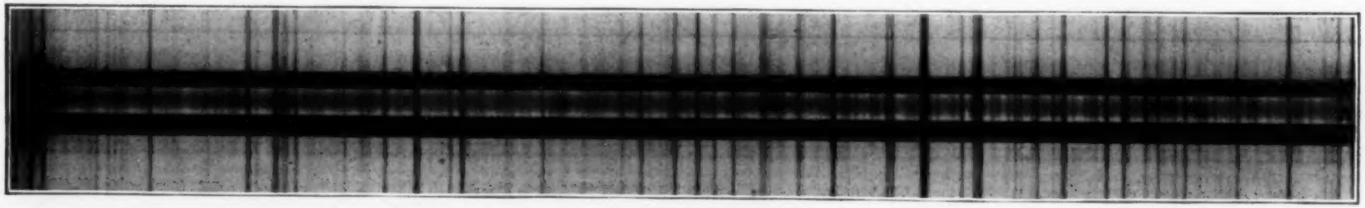


FIG. 2.—Region λ5085–λ5165

Plate IV could exist. The remarkable strengthening of some of the lines of certain elements, and the perhaps even more remarkable reduction in intensity of some of the lines of other elements, gives to spot spectra a very exceptional interest, and should encourage the most careful investigation, both by visual and photographic means.

Our photographs tend to confirm the view expressed by Young, Dunér, and Fowler, that the bright lines described by Young are simply interruptions in the series of dark lines, corresponding to similar interruptions in the general solar spectrum. As for the character of the fine lines in the spot spectrum, to which Mitchell calls special attention, our photographs are not as well suited as visual observations to determine a question of this kind. We hope to return to this and various other questions at a later date.

Of course, it does not follow from our discussion that true bands or flutings do not exist in the spectra of sun-spots. We can only say that we have so far failed to record them, and that many of the so-called "bands" are undoubtedly due to the fine lines shown in our photograph.

Table III contains the detailed results of Mr. Adams' measures, together with the estimates of intensity. The means derived from the separate plates are then compared with Rowland's values. The column R. – M. (Rowland – Mean) gives the differences between the wave-lengths of the lines in Rowland's table, with which we identify our lines, and our mean values, the unit being 0.01 tenth-meter. In the last column the probable identifications with Maunder's bands are added.

A considerable number of blends are included in the table. It will be seen that in almost every such case the line is noted as "broad" in the last column. These notes are taken from the original record books, and indicate that the compound character of the line is shown by its unusual width.

THE CAUSE OF THE DARKNESS OF SUN-SPOTS

In a paper with the above title,[1] Mr. Evershed expresses the opinion that the darkness of sun-spots cannot be accounted for as the result of absorption alone. He cites the explanation of Maunder

[1] *Astrophysical Journal*, 5 244, 1897.

TABLE III

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5032.56	.54			00	00			5032.55	00	5032.56	000N	+1	These lines with 5032.09
5033.78	.76			0	0			5033.77	0	5033.77	000 000	0	5032.91 are Maunder's 5033.0
5034.41	.42			00–0	00–0			5034.42	00–0	5034.43	000 0000	+1	Broad
5034.68	.68			00	00			5034.68	00				
5035.10	.09			00	00			5035.10	00				
5042.76				000				5042.76	000				
5043.08				0				5043.08	0				
5043.51				00				5043.51	00	5043.48	000	−3	
5044.97	.97			00	00			5044.97	00	5044.94	0000N	−3	
5046.37				00–0				5046.37	00–0	5046.38	000N	+1	
5047.14				0				5047.14	0	5047.11	000	−3	Narrow
5049.39				0				5049.39	0	5049.38	0000	−1	
5054.23				0				5054.23	0	5054.26	000	+3	Maunders 5054.7
5056.15				00–0				5056.15	00–0	5056.17	*Fe*00	+2	Maunder' 5056.7
5056.59				0				5056.59	0	5056.62	000	+3	
5059.10	.08			00	00			5059.09	00	5059.11	0000	+2	Narrow
5059.41	.44			00	00			5059.42	00	5059.41	000	−1	Maunder's 5059.2
5060.65				00–0				5060.65	00–0				
5061.56				00				5061.56	00	5061.58	000	+2	
5061.92				0				5061.92	0	5061.88	00	−4	
5063.71	.71			0–1	0–1			5063.71	0–1	5063.70	0000	−1	
5064	.03				00			5064.03	00	5064.06	0000	+3	
5065.89				00				5065.89	00	5065.89	0000	0	
5071.32				00				5071.32	00	5071.31	000	−1	
5081.76				00				5081.76	00	5081.76	000	0	
5082				0				5082	0	5081.98	000 000	−2	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5083.20				o				5083.20	o	5083.20	oooNd	o	
5084.80				oo–o				5084.80	oo–o	5084.80	ooo ooo	o	Broad
5085.03				oo				5085.03	oo	5085.02	ooo	−1	
5086.05				oo				5086.05	oo	5086.08	*Cd* ?ooooN	+3	Maunder's 5086.4
5086.81				o				5086.81	o	5086.79	oooo	−2	
5089.38				o				5089.38	o	5089.39	oooNd ?	+1	
5090.01				oo				5090.01	oo	5090.00	oooo	−1	Maunder's 5090.4
5090.57				oo				5090.57	oo	5090.57	oooo	o	
5091	.48	.48	.48		oo	oo	oo	5091.48	oo	5091.48	oooo	o	Narrow
5092.76	.76	.77	.77	o	o	o	oo	5092.76	o				Probably Maunder's 5093.0
5092.96				oo				5092.96	oo	5092.98	ooo	+2	
5093.79	.77	.78	.76	o	o	oo–o	oo–o	5093.78	o				Maunder's 5093.7
5095.97	.97	.99	.97	o	o	o	o	5095.97	o	5095.95	oooo ooo	−2	Broad
5096.37	.40			o	oo–o			5096.38	oo–o	5096.36	ooo	−2	Maunder's 5096.2
5096		.49	.51			1	o–1	5096.50	o–1	5096.49	ooo oooo	−1	Broad
5100.66	.63	.63	.63	oo	ooo	oo	oo	5100.64	oo	5100.64	oooo	o	
5101.17	.19	.19	.20	o	oo	oo–o	oo–o	5101.18	oo–o	5101.18	ooo ooo	o	
5101.64	.63	.61	.62	oo–o	oo–o	oo	o	5101.63	oo–o	5101.66	ooo	+3	
5102.16				oo				5102.16	oo	5102.18	oooo	+2	
5102.40				oo				5102.40	oo	5102.40	oooo	+1	
5108.82	.81	.81	.84	o	oo	oo	oo	5108.82	oo	5108.80	oooo	−2	
5109.26				o				5109.26	o	5109.29	oood ?	+3	
5111.16				oo				5111.16	oo	5111.14	oooo	−2	
5111.49	.51	.52	.51	oo	oo	oo	ooo–oo	5111.50	oo	5111.49	oooo ooo	−1	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.–M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5111.84	.84	.84	.87	o	oo–o	oo–o	o	5111.85	o	5111.85	ooo oooo		Broad
5112.34		.36		oo		oo		5112.34	oo				
5112.80	.80	.80	.79	oo–o	o	o	o	5112.80	o	5112.82	ooooN	+2	
5114.19		.22	.21	o–1		o	o	5114.20	o	5114.20	ooooN	o	
5114.70		.70	.71	o		oo–o	oo–o	5114.70	oo–o	5114.68	oooNd ?	–2	
5116.33		.27	.26	oo–o		oo	oo	5116.30	oo	5116.29	oooo oooo	–1	
5116.62		.64	.66	1		o–1	o–1	5116.64	o–1	5116.64	oooo	o	
5117.02		6.98	6.98	o		oo–o	o	5117.00	o	5117.01	ooo ooo	+1	Maunder's 5116.9
5118.51	.50	.51	.51	o–1	oo–o	oo–o	o	5118.51	o	5118.53	oooo	+2	
5118.98	9.00	.98	9.01	1	1	o	o–1	5118.99	o–1	5118.99	oooNd ?	o	Maunder's 5118.7
5119.52	.54	.53	.55	o	oo–o	oo	oo–o	5119.53	oo–o	5119.56	ooo	+3	
5119.95	.93	.93	.92	oo–o	oo	oo	oo	5119.94	oo	5119.94	oooo	o	
5120.26	.30	.31	.31	oo	oo	oo	oo	5120.29	oo	5120.28	oooo	–1	
5121.13		.10	.11	oo–o		oo	oo	5121.12	oo	5121.13	oooo	+1	Maunder's 5121.0
5121.41				oo–o				5121.41	oo–o	5121.41	oooo	–1	
5122		.39		o	o	o	o	5122.39	o	5122.37	oooo ooo ooo	–2	Very broad
5124.67		.69	.70	o		o	o	5124.68	o	5124.70	ooo oo	+2	Broad
5125.73	.71	.73	.70	oo	oo	oo	oo	5125.72	oo				
5126.02				oo				5126.02	oo	5126.01	oooo	–1	
5127.11				oo–o				5127.11	oo–o	5127.10	oooo oo	–1	Broad
5128		.72				o		5128.72	o	5128.72	ooo oooo	o	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5131.12				00–0				5131.12	00–0	5131.10	0000	−2	
5132.32	.34	.37	.37	0	00–0	0	0–1	5132.34	0	5132.34	0000	0	
5133.11	.09	.06	.07	00	00	00–0	00–0	5133.09	00	5133.12	000	+3	
5133.34				0				5133.34	0	5133.36	000	+2	
5134.49		.48	.47	1		0–1	0–1	5134.48	0–1	5134.50	0000	+2	
5134.79		.80	.80	1–2		1–2	2	5134.79	1–2	5134.76	000 0000	−3	Broad
5135.28		.31	.34	1		0–1	1	5135.30	1	5135.31	0000 0000	+1	
5135		.84	.82			00	00–0	5135.83	00	5135.82	000*C*, – 000*C*, –	−1	Broad
5136.65	.66	.65	.66	00–0	00	00–0	0	5136.65	00–0	5136.62	0000	−3	
5138.59	.59	.57	.57	0	0–1	0–1	0–1	5138.58	0–1	5138.60	0000 0000	+2	Broad
5138.97	.95	.96	.96	0	0	0	0	5138.96	0	5138.95	000 0000	−1	Broad
5140.46	.45	.40	.41	0–1	0	0–1	1	5140.44	0–1	5140.44	0000 0000	0	Broad
5141.45	.39	.35	.36	0–1	0–1	0–1	1	5141.40	1	5141.43	000*C*, – 0000	+3	Broad
5143.85	.83	.81	.81	1	1	0–1	1–2	5143.83	1	5143.85	000 00	+2	
5144.21	.24	.20	.20	0–1	0–1	0–1	1	5144.21	0–1	5144.20	0000	−1	
5145.93	.94	.94	.91	0	00–0	00	00–0	5145.93	00–0	5145.91	0000N	−2	Narrow
5148.91	.93	.94	.94	1	0–1	1	1	5148.93	1	5148.93	000 000	0	Broad
5149.66	.67	.68	.68	0–1	0–1	0	0–1	5149.67	0–1	5149.68	0000N	+1	
5149.97	0.01	0.00	.99	0	00–0	00–0	00–0	5149.99	00–0	5149.96	000	−3	
5150		.37	.36			1	0–1	5150.36	0–1	5150.36	00	0	

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5151.36	.36	.37	.38	00	000	000	000	5151.37	000	5151.34	0000N	−3	Narrow
5151.63	.64			000	000			5151.63	000	5151.63	0000N	0	
5152		.82	.81			00	00	5152.82	00				An unresolved band fills the space between the lines 5154.24 and 5155.30
5156		.54	.52			00	00	5156.53	00	5156.53	000	0	
5157.20	.21	.20	.21	00	00–0	0	00–0	5157.20	00–0	5157.16	0000	−4	
5157.78		.79	.81	00		0	0	5157.79	00–0	5157.78	000–,*C*	−1	
5158.51	.48	.50	.48	000	00	00	00	5158.50	00				Narrow
5158.80	.82	.82	.80	0	00–0	0	0	5158.81	0	5158.83	0000,*C*	+2	
5159.97	.96	.97	.94	0–1	0	1	0–1	5159.96	0–1	5159.95	0000	−1	
5160.39	.38	.38	.40	0–1	0	1	1	5160.39	0–1	5160.42	00N*C*,–	+3	
5163	.11	.11	.09	2	1–2	2	2	5163.10	2	5163.07	000*C*,–	−3	Very broad
5163	.79	.81	.78		00–0	0	0	5163.79	0	5163.76	000*C*,–	−3	
5168		.36	.34			00	00	5168.35	00	5168.36	000Nd ?	+1	
5169	.64	.65	.69		000	000	000	5169.66	000	5169.66	0000	0	
5170	.26	.25	.25		000	000	000–00	5170.25	000	5170.27	0000	+2	
5170.74	.80	.80	.80	0	0	0	00–0	5170.78	0	5170.77	000	−1	
5171.20	.20	.21	.20	00–0	00–0	00	00–0	5171.20	00–0	5171.19	0000	−1	
5175.10	.11	.13	.14	0	00–0	00	00	5175.11	00	5175.10	000	−1	
5175.59	.54	.55	.54	0	0	00–0	00	5175.56	00–0	5175.58	000	+2	
5175.92	.93	.94	.95	00–0	00	00	000	5175.93	00	5175.92	000Nd ?	−1	
5176.30	.31	.31	.31	0	00–0	00–0	00	5176.31	00–0	5176.30	000	−1	
5178.66	.69	.67	.66	00	00	00–0	00–0	5178.67	00	5178.64	000	−3	
5180		.68	.65			0	0	5180.66	0	5180.66	{ 000 000	0	
5185		.21	.21			00	000	5185.21	000–00	5185.20	0000	−1	
5186			.53				00	5186.53	00	5186.50	000N *Fe*	−3	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 20	L 20	L 19	L 08	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5187		.64	.62			00	00	5187.63	00	5187.62	000	−1	
5190		.36	.34			0	00–0	5190.35	00–0				
5190		.74	.72			00–0	0	5190.73	00–0				Narrow
5193		.61	.61			00–0	00	5193.61	00	5193.60	0000 000	−1	Broad
5194		.14	.14			0–1	1	5194.14	0–1	5194.14	0000 000	0	Broad
5198		.51	.52			00	00	5198.52	00	5198.51	0000	−1	Narrow
5199		.79	.79	1	0	0–1	0	5199.79	0–1	5199.77	000	−2	
5201		.78	.82	00	0	00–0	00–0	5201.80	00–0	5201.77	0000	−3	
5203		.65	.67	0	0	0	00–0	5203.66	0	5203.66	000	0	
5211		.03	.02			0	0	5211.02	0	5211.02	000	0	
5212		.43	.44		0	0–1	0	5212.44	0	5212.44	000N 0000	0	Broad

that a spot may be considered as a region of high temperature, where the condensation of carbon (or some similar element) does not take place to the same extent as in the photospheric clouds. The diminished radiation would then be due, according to Maunder, to the lower emissive power of the gaseous contents of the spot. Evershed recognizes, however, the fundamental defect of this explanation, viz., that the radiation from a sufficient thickness of such intensely hot gas would be as great as that from a theoretical "black body," thus actually exceeding the radiation of the photospheric clouds. He endeavors to escape this difficulty by assuming that the maximum of intensity in the spectrum of this gas would be displaced into the extreme ultra-violet. The position of the maximum in the spot spectrum would then furnish the means of deciding between the two views.

Liveing and Dewar made a similar suggestion in 1883,[1] but E. Weidemann pointed out that, although the intensity of a luminous source increases most rapidly in the more refrangible region as the temperature rises, the intensity of the less refrangible region also increases.[2]

Dr. W. E. Wilson, who also believes that the darkness of a sun-spot is principally due to deficiency of radiation rather than to absorption, offers a suggestion advanced by the late Professor Fitzgerald for the purpose of getting over the difficulty. Professor Fitzgerald believed that great convection currents must exist within such a gaseous layer as that seen in a sun-spot, and that these would scatter a large amount of light, and thus prevent it from reaching the surface. Hence the effective radiation would be limited to a layer not deep enough to give the effect of a "black body," and the spot would appear dark.[3]

The evidence brought in the present paper, in addition to that previously furnished by visual observations, leaves no doubt in our

[1] *Phil. Mag.*, 5th series, **16**, 402, 1883.

[2] Ibid., **17**, 247, 1884.

[3] *Monthly Notices*, **65**, p. 325, 1905. Wilson, in another paper, describes an experiment in which the radiation of an arc, in a gas at high pressure, was greatly reduced by the effect of convection currents caused by suddenly releasing the pressure (*Proc. Royal Society*, A **76**, 375, 1905).

minds that absorption is to be regarded as the principal cause of the darkness of sun-spots. A mere reduction of the intensity of the solar light, due to diminished radiation, could not, in our opinion, account for the observed phenomena. In describing his artificial spot spectrum,[1] Wilson states that all lines with nebulous edges are widened, while sharp lines are not affected. In answer to this, it may be said, on the one hand, that the lines which are widened in sun-spots are not all nebulous, and, on the other hand, it frequently happens that certain very faint lines are greatly increased in intensity, while other faint lines of the same element are not affected.

It is true that Wilson, in his recent paper, does not ascribe the widening of the lines in sun-spots entirely to the want of brightness of the gaseous layer below; he considers that the greater depth of the observed vapors of certain elements, such as titanium, whose atomic weight might determine their position between the photosphere and an underlying gaseous layer, would cause the lines of these substances to be specially conspicuous in the spot spectrum. We have already pointed out that all of the lines of such elements are not equally enhanced, but it might be said that this fact can be no more easily explained on the basis of the ordinary absorption hypothesis. We must therefore have recourse to some other test.

The necessary criterion seems to be afforded by certain determinations of the intensity of radiation of sun-spots corresponding to the light of different wave-lengths, made by Mr. Abbot on Mount Wilson during the past summer, as a part of the work of the Smithsonian Expedition. Without going into the details of these observations, which will doubtless be published in full at a later date, it may be said that the radiation of sun-spots, as compared with that of the photosphere, decreases very rapidly with the wave-length. In the infra-red the radiation of the umbra of a sun-spot is but little below that of the surrounding photosphere, whereas at the violet end of the spectrum the relative intensity of the photospheric radiation is far greater.

[1] Wilson produced a dark line spectrum by passing the light from a luminous globe through the fumes of nitrous oxide. A piece of thin paper pasted to the globe cut down the intensity of the light about 50 per cent., and its image on the slit produced a dark band in the spectrum, across which the diffuse lines were widened.

There can be no doubt, as von Oppolzer has pointed out, that the increase of temperature is extremely rapid in passing from the level of the photosphere toward the center of the Sun. Adopting his minimum estimate of an increase of 6000° C. for one second of arc, and applying Wien's law,[1] we find that the maximum of intensity in the spot spectrum would be shifted to a position not far from λ 2300, if the radiation were supposed to come from a region whose mean level is one second below the photosphere. Since Mr. Abbot's observations show that the maximum of intensity, which is at λ 4900 in the spectrum of the photosphere, is shifted in spots far into the infra-red, we might ascribe such a shift, whatever the source of the continuous spectrum, to the great absorption of the gases which constitute the umbra, and perhaps also to their comparatively low temperature. Leaving the question of temperature for discussion in a future paper, we may say that the radiation measures are entirely in harmony with the visual and photographic observations of spot spectra. The greatly increased absorption, shown by the marked intensity of the innumerable lines in the spot spectrum, would undoubtedly produce a decided shift of the maximum toward the infra-red. We therefore believe that the darkness of sun-spots may be sufficiently well accounted for by absorption alone.

[1] The equation

$$\lambda \text{ max.} \times \text{abs. temp.} = \text{const.}$$

gives 6000° C. as the temperature of the photosphere, when Abbot's value of 0.49 μ for λ max., and Lummer's value of 2940 for the constant (corresponding to a "black body") are used. If the constant is taken as 2630, determined by Lummer for platinum, the temperature of the photosphere comes out 5700° C. In computing the wave-length of the maximum for a point one second below the photosphere, we have employed these smaller values.

MOUNT WILSON,
December 1905.

SOME NOTES ON THE H AND K LINES AND THE MOTION OF THE CALCIUM VAPOR IN THE SUN[1]

By WALTER S. ADAMS

The importance of the H and K lines of calcium in the study of solar spectroscopy has been growing steadily greater within recent years. Their remarkable behavior over the general surface of the Sun, in prominences and over spots, would make them the most interesting lines in the solar spectrum even if we did not consider the fact that they are the chief, and for many instruments the only, lines which can be used with the spectroheliograph in mapping the surface of the Sun. Accordingly it may be of interest to describe some special studies on these lines which the writer has been carrying on, and to state some of the results obtained.

The spectroscope which has been employed is of the Littrow form, consisting of a 3¼-inch (83 mm) plane grating used in connection with a 4-inch (102 mm) lens of 18 feet (5.5 m) focal length. The image-forming instrument, in the case of the majority of the plates, has been a 6-inch (152 mm) lens of 62 feet (19 m) focal length, used in connection with a small coelostat. This gives an image about 7 inches (17.8 cm) in diameter. A few of the recent plates have been obtained with the Snow horizontal telescope, in which an image of the same size is formed by means of a concave mirror. When the spectroscope was transferred to the latter instrument, the modification was introduced of placing the photographic plate above, instead of to one side of the slit, with a view to making any aberration due to the slight tilting of the lens act along the lines instead of across them. The definition, which has always been excellent, seems to remain unaltered. Almost all of the plates have been obtained in the spectrum of the third order, which is bright in this grating, and sufficiently high to give full photographic resolution. The scale in this order is almost exactly one millimeter to the tenth-meter, or about the same as that of the original negatives used by Rowland in his map of the solar spectrum.

[1] *Contributions from the Solar Observatory*, No. 6.

An accurate knowledge of the wave-lengths of H and K in the arc spectrum is essential for any investigations of these lines in the Sun, and here there seems to be considerable discordance among the values given by different observers. The best of these would seem to be:

	K	H
Rowland	3933.809	3968.617
Kayser and Runge	3933.83	3968.63
For the spark between poles of calcium:		
Eder and Valenta	3933.803	3968.638

In order to make these values comparable with the solar spectrum wave-lengths of Rowland's "Preliminary Table," the erroneous correction applied by Rowland to all of his arc standards has to be compensated. The value of this correction as given by Hartmann, after smoothing out Jewell's measures by means of a curve, amounts to -0.010 for K and -0.011 for H. The application of these corrections gives:

	K	H
Rowland	3933.799	3968.606
Kayser and Runge	.82	.62
Eder and Valenta (spark)	.793	.627

In view of these discrepancies, it seemed to me desirable to obtain some measures, and for this purpose I made a number of photographs of the H and K lines, using as a source the carbon poles of an electric arc moistened with a solution of calcium chloride, and in some cases also employing an iron terminal for the sake of the comparison spectrum. The appearance of the H and K lines produced in this way is well known, that of a sharp, narrow absorption line lying upon a strong, bright band whose width depends upon the amount of calcium vapor present. The measures were, of course, made upon the absorption line.

The first four plates were reduced with Rowland's values for the aluminium lines and λ 3973, and Kayser's value for the iron line, λ 3928. The last eight plates were reduced with the use of Kayser's iron standards wholly. As Kayser's and Rowland's systems are

entirely homogeneous, this procedure is evidently quite correct. Each of the values of H and K rests upon two standard lines, and the largest value of a residual found for a standard upon any one of the plates is +0.007. The results of the measures are as follows:

	K		H
	3933.819		3968.630
	.820		.625
	.823		.631
	.820		.632
	.816		.631
	.816		.625
	.819		.629
	.815		.629
	.820		.625
	.815		.630
	.817		.629
	.818		.629
Mean	3933.818	Mean	3968.629

Applying the previous corrections to these values, we find for direct comparison with the wave-lengths of the lines in the solar spectrum:

K	H
3933.808	3968.618

The solar photographs which were measured include some which were made with the slit upon the general disk and others across spots. The approximate position of the slit upon the Sun has been noted in all cases. The narrow absorption line has always been measured, and in a considerable number of cases the bright components as well, although these measures are much more difficult. It is evident, if a is the wave-length of one of these components, and d the difference of wave-length between the absorption line and the second component, that the center of the whole bright line is given by $a+d$.

The following table contains a list of the measures. K_3 is used for the central absorption line, and V K_2 and R K_2 stand for the violet and red components of the bright line, respectively, according to the notation introduced by Hale. The plates are grouped according to the position of the slit on the disk of the Sun, whether near the center, limb, or, roughly, midway between. The method of

reduction followed has been the same as that in the case of the arc spectrum measures, each line depending upon two standards. The largest residual found is less than 0.01 tenth-meter. The plates are given arbitrary numbers, and the letters following the numbers refer to separate exposures in regions of the Sun which lie close together. In a few cases different points along the lines on a single exposure have been measured, and these are denoted by figures in brackets.

MEASURES ON DISK

Plate	K_3	H_3	H_3-K_3	K_2	H_2	H_2-K_2	Remarks
Near Center							
1 a.....	3933.797	3968.615	0.018	3933.798	3968.621	0,023	$V K_2=R K_2$
b.....	.809	.617	.008	.807	.620	.013	$V K_2=R K_2$
2 a (1)..	.805	.617	.012	.802	.616	.014	$V K_2=R K_2$
(2)..	.803	.620	.017	.796	.619	.023	$V K_2=R K_2$
(3)..	.798	.615	.017	.793	.606	.013	$V K_2=R K_2$
(4)..	.800	.618	.018	.796	.607	.011	$V K_2=R K_2$
One-half Center to Limb							
3 a.....	.807	.622	.015	.799	.815	.016	$V K_2=R K_2$
b (1)..	.793	.601	.008				
(2)..	.800	.616	.016				
c (1)..	.797	.604	.007				
(2)..	.776	.588	.012				
(3)..	.815	.627	.012				
d (1)..	.806	.610	.004				
(2)..	.792	.610	.018				
Near Limb							
4 a.....	.810	.620	.010				
b.....	.813	.620	.007	.798	.617	.019	$V K_2>R K_2$
5 a (1)..	.810	.626	.016	.805	.622	.017	$V K_2=R K_2$
(2)..	.803	.622	.019	.810	.625	.015	$V K_2>R K_2$
b.....	.805	.609	.004				
c......	.808	.611	.003				
6 a.....	.798	.611	.013				
b.....	.804	.609	.005				
c......	.800	.613	.013				
d.....	.801	.607	.006				

MEASURES OVER SPOTS

K_3 and H_3 Bright and Single

Near Center

7 a.....	.809	.625	.016				

Near Limb							
8 a.....	.810	.619	.009				
b.....	.815	.620	.005				
c......	.808	.611	.003				
K_3 and H_3 Dark and Narrow Near Center							
9 a.....	.806	.613	.007	.800	.606	.006	
b.....	.799	.610	.011	.789	.606	.017	
c......	.795	.603	.008	.794	.601	.007	
			0.011			0.015	

The most striking feature of these results is the general tendency toward a displacement to the violet. The average wave-length of K, for the measures on the disk, is 3933.802, and of H 3968.612, and the persistence of the direction of displacement among the separate values makes this almost unquestionably real. Taking the values already found for the wave-lengths of H and K in the arc spectrum, the average displacement amounts to 0.006 tenth-meters, which would mean a velocity of approach on the part of the calcium vapor producing the absorption lines of 0.41 kilometers a second. In taking this average, however, it is by no means intended that the conclusion should be drawn that the ranges among the separate plates are accidental. That these are due to actual differences of motion is shown not only by the fact that they considerably exceed the degree of accuracy attained in the measures, but also from a consideration of single plates, such as 3 c. In this plate we find a range of 0.039 tenth-meters for both H and K, between two points at a short distance from one another, and this is visible to the eye in a decided bending and slant of both the emission and the absorption lines. No certain evidence can be found in these observations of any such variation in the motion of the calcium vapor between the center and the limb, as might be expected from a general drift upward in a radial direction. A large amount of material will, however, be necessary before any conclusion can be drawn in regard to this matter.

The result found above, of a displacement of the absorption lines toward the violet, is opposed to Jewell's conclusion that the vapor

producing these lines is descending toward the surface of the Sun. In regard to this matter, he says[1]:

> The narrow central component of the shaded lines shows a descending motion over the solar surface of the absorbing matter producing it . . . . of about a mile a second in the case of the H and K lines. The velocity in the case of the H and K lines is decidedly variable. . . . . These narrow components of the shaded lines are probably produced by meteoric matter falling into the solar atmosphere.

This contradiction of results seems to lie largely in the difference of wave-length assigned to the arc lines in the two cases. Jewell gives the values:

K	H
3933.794	3968.603

It would be of interest to know what standards were employed in the derivation of these values, but no information is given on that subject. That the choice of standards may vitally affect the results is shown by the difference in wave-length amounting to 0.013 tenth-meters assigned by Kayser and by Rowland to the iron line at λ 3928.

The results given by the emission lines, H_2 and K_2, also show a displacement toward the violet, although the measurement of these lines is much more difficult than that of the absorption lines. In this respect they confirm the conclusion formed by Jewell, although no quantitative determinations were made by him. Upon most of the plates which were measured the violet and the red components are very nearly equal; in several the violet is slightly stronger, and in one distinctly weaker than the red component. This last condition is known to be decidedly rare.

The measures given in the above table of bright K_3 and H_3 over spots show some slight indication of a longer wave-length than on the general surface. It would need a much larger number of observations to establish this, however, as the lines are wide and hazy and much more difficult to measure accurately than the absorption lines. The other measures over spots, in which K_3 and H_3 appear as dark lines between bright components, probably belong strictly to the series of measures on the disk. They were made over small spots on which photospheric light evidently encroached sufficiently to produce the characteristic appearance of the lines on the disk rather

[1] *Astrophysical Journal*, 11, 237, 1900.

than the single bright lines which are peculiar to spots. This same effect is found in photographs of spectra of very small spots in the yellow and green region, when very little of the characteristic spot spectrum is likely to be found unless the solar definition is extraordinarily fine.

In a recent number of *Comptes Rendus*,[1] M. Deslandres states some conclusions derived by him from an examination of a number of photographs of the K line. These were obtained with his *spectrographe des vitesses*, an instrument which by means of an interesting attachment is so moved as to give on a single plate a record of a narrow strip of spectrum at a large number of successive points on the Sun's surface. In discussing these plates M. Deslandres says that at the center of the disk the two bright components of K_2 are unsymmetrical, with the red component the narrower. From this displacement of the absorption line K_3 in reference to the emission line K_2 he draws the conclusion that the vapor producing K_3 is descending, and the vapor producing K_2 is ascending. It is evident that this conclusion is by no means justifiable since the displacement of one line in reference to the other indicates only relative motion, and can have no bearing on the question of the absolute motion of the vapor giving rise to either line. The latter can be determined only from comparison with the spectrum from an artificial source, as has been done by Jewell and in this paper.

In stating that at the center of the disk the components of K_2 are unsymmetrical it appears to the writer that M. Deslandres makes too broad a generalization. In the case of each of the plates discussed in this paper which were taken at the center of the disk the components are apparently quite equal. A similar contradiction is found at the limb, where, in M. Deslandres' opinion, the lack of symmetry disappears. Two out of three of the plates which were measured show the violet component of K_2 to be decidedly the stronger. It seems probable that, while an effect like that found by M. Deslandres is perhaps to be expected, the local conditions of the calcium vapor at different points on the Sun's surface vary so much as to mask it completely in many cases. Evidence of this is found in

[1] 141, 7, 377, 1905.

spectra taken with a slit of considerable length; the components vary greatly at different points and often by unequal amounts.

One of the most important conclusions to be drawn from this series of measures is in regard to the relative wave-lengths of H and K. Rowland gives for these two lines in the solar spectrum:

$$\overset{\text{K}}{3933.825} \quad \overset{\text{H}}{3968.625}, \text{ or } H-K=34.800$$

The values found in this investigation give the following differences:

Arc Spectrum	34.810
K_3 and H_3	34.811
K_2 and H_2	34.815

The last value is, of course, much less accurate than the others, but is certainly confirmatory of them. There is accordingly little doubt that in the Sun the relative wave-length as given by Rowland, of H as referred to K, is in error by about 0.010 units. It is, of course, equally evident that no definite wave-length can be assigned to these lines in the solar spectrum, since the vapor giving rise to them has different motions on different parts of the Sun's surface.

In considering the variations in the position of these lines as due to motion alone, the possible effect of pressure has been neglected. As Jewell has already shown, however, it is clear that the effect of pressure in the region of the solar atmosphere producing the absorption lines, K_3 and H_3, must be extremely slight. In the case of K_2 and H_2 it may be sensible, and partially compensate a still larger shift of these lines in the direction of shorter wave-lengths.

In conclusion, it ought to be stated that a very large amount of observational material will be necessary to determine the laws of motion of the calcium vapor over the surface of the Sun. Even with very powerful apparatus, the measures are delicate and complicated by the changing character of the lines. The value of such determinations toward the interpretation of spectroheliograph results will be very great, however, and similar studies on other lines, notably those of hydrogen, sodium and iron, would assist materially in determining the structure of the Sun's atmosphere.

NOTE ON H_ϵ

On a photograph taken October 27, 1904, with the slit crossing a

group of small spots, the ϵ line of hydrogen appeared as a broad, hazy, bright shade across two of the spots, and a narrow bridge between them. As this is a very rare observation, measures were made on the four separate exposures upon the plate, with the following result:

$$\begin{array}{r} 3970.175 \\ .165 \\ .167 \\ .169 \\ \hline 3970.169 \end{array}$$

The agreement of the separate measures is rather illusory, the line being excessively hazy and ill-defined, as well as a full tenth-meter in width. The result agrees, however, with the value given by Rowland, which is considerably smaller than that found by most eclipse observers.

Solar Observatory,
Mount Wilson, Cal.,
November 1905.

THE FIVE-FOOT SPECTROHELIOGRAPH OF THE SOLAR OBSERVATORY

BY GEORGE E. HALE AND FERDINAND ELLERMAN

In a recent paper[1] we have described the spectroheliograph designed for use with the 40-inch Yerkes refractor. As stated in this paper, the most satisfactory form of spectroheliograph is that in which the instrument is moved as a whole, while the image of the Sun and the photographic plate are stationary. The first spectroheliograph of this type was constructed in 1893, from Mr. Hale's general design, by Toepfer, of Potsdam, and employed in some attempts to photograph the solar corona without an eclipse, from the summit of Mount Etna.[2] In the case of the Rumford spectroheliograph, it was necessary to produce the motion of the Sun's image across the first slit by driving the telescope tube at a uniform rate in declination, the photographic plate being moved at the same time across the second slit. From a mechanical point of view, such an instrument is not an entirely satisfactory one, but the Rumford spectroheliograph has nevertheless given good photographs, some of which are reproduced in our paper.

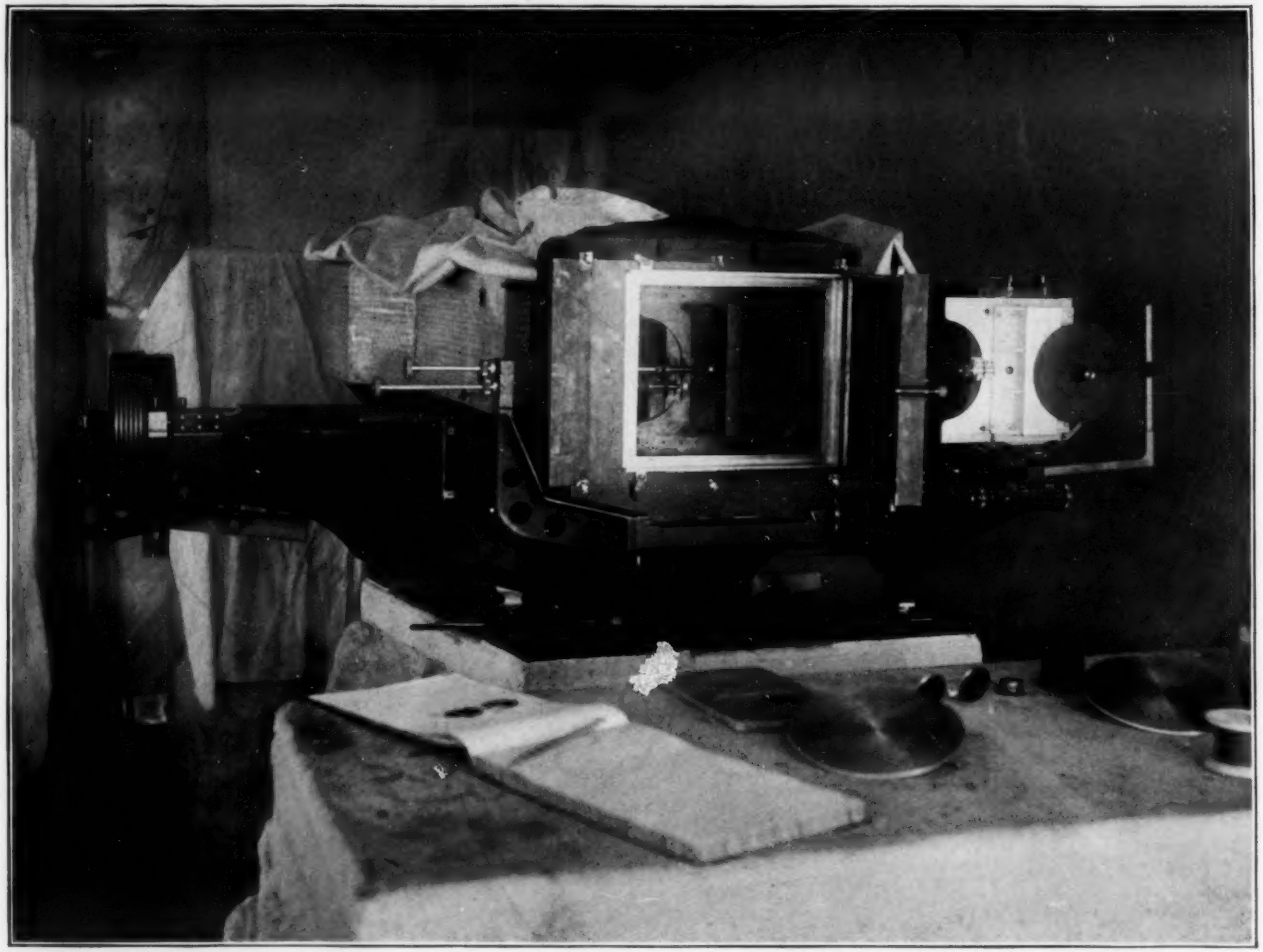
As soon as arrangements had been made to erect the Snow telescope on Mount Wilson, it became possible to design, for use with it, a spectroheliograph of the type employed on Mount Etna. We were fortunate in having the assistance of Professor Ritchey and Mr. Pease, whose skill in working out the details of construction has been demonstrated by the very satisfactory operation of the instrument.

A photograph of the spectroheliograph, mounted for use with the Snow telescope, is reproduced in Plate VI. A better idea of the general design may be obtained from Plate VII, which shows the spectroheliograph in our instrument shop before it was completed. It consists essentially of a massive cast-iron base, bearing four short Λ-rails at its four corners, on which the moving part of the instrument

[1] "The Rumford Spectroheliograph of the Yerkes Observatory," *Publications of the Yerkes Observatory*, 3, Part 1.

[2] *Astronomy and Astro-Physics*, 13, 662, 1894.

PLATE VI



THE FIVE-FOOT SPECTROHELIOGRAPH MOUNTED FOR USE WITH THE SNOW TELESCOPE

is carried by four steel balls. The cast-iron platform which bears the slits and optical parts has four inverted ʌ-rails which rest on the steel balls, but almost its entire weight is supported by mercury, in three tanks formed by subdivisions in the base casting. Wooden floats extend from the lower surface of the iron platform into these tanks, reducing to a minimum the amount of mercury (about 560 lbs. = 254 kg) required to bear the instrument. The motion of this platform with respect to the fixed solar image and photographic plate is produced by either one of two screws of different pitch, driven by an electric motor arranged to give wide variation in speed.

Slits.—The first and second slits represent marked improvements over the slits employed in the Rumford spectroheliograph. They are each 8½ inches (21.6 cm) long; one jaw is fixed, and the other can be moved by a micrometer screw. The second slit can also be moved as a whole across the end of the camera, so as to permit it to be set accurately upon any spectral line after this has been brought near the center of the field by rotating a mirror in the optical train. Both slits are of very massive construction, so as to reduce the danger of flexure. The jaws are heavy castings of bronze, and the guides, in which one jaw of each pair slides, are very accurately made. The slits are so mounted that they can be rotated in their own plane by a screw, thus permitting the first slit to be placed parallel to the refracting edge of the prisms, and the second slit to be made parallel to the spectral lines. The iron castings which carry the slits can be easily removed from the collimator and camera tubes, when it is desired to substitute other slits of different curvature. The clamping screws, and the stops which determine the position angle of the slits, are so constructed that they can be released in a moment, while they define the position of the slits so accurately that no change in adjustment is required when the slits are returned to their places. The collection of slits already provided for the spectroheliograph includes one straight slit and five slits of different curvatures, required for use with either two or four prisms and for different spectral lines. Additional curved slits are constructed as the need for them arises.

The method of correcting the distortion of the solar image, which arises from the use of a straight first slit and a curved second slit,

is the same as that employed in the Rumford spectroheliograph: the curvature is equally divided between the first and second slits, in accordance with a suggestion made by Wadsworth some years ago. It must be borne in mind that this method is effectual only in cases where an odd number of reflections occur in the optical train (see p. 58).

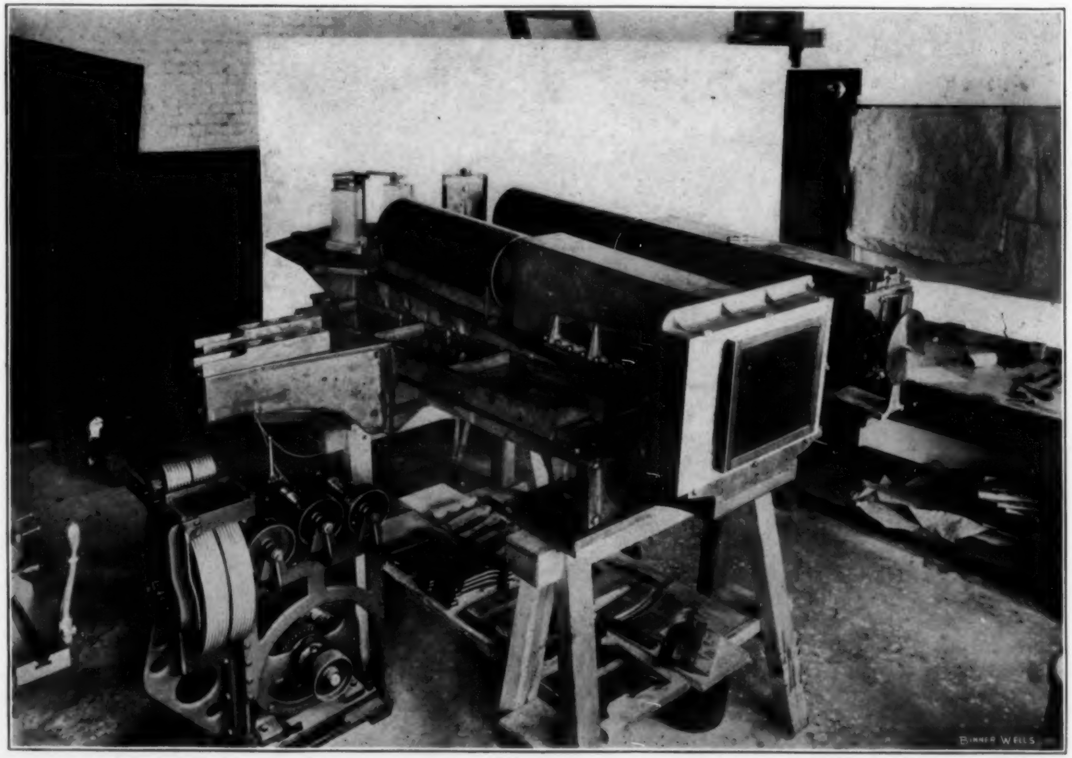
It is important that the second slit should be provided with means of varying its width and changing its position when the photographic plate is in place. For example, it may be desired to make a series of photographs of the flocculi surrounding a sun-spot, corresponding to different widths of the second slit and to different positions of this slit on the H_1 band. For this purpose, as Plate VI shows, the micrometer screws are provided with extension rods, which can be turned from outside the light-tight box that incloses the plate-holder. These extension rods are furnished with micrometer heads, so that the exact position and width of the slit can be read without opening the box.

FIG. 1.—Section of Second Slit-Jaws.

The jaws of the first slit are silver-plated, and when the instrument is in use a light screen of aluminium, pierced by a long narrow window, is mounted a short distance in front of this slit. Without these precautions, as our experience with the Rumford spectroheliograph showed, the heating of the jaws by the large solar image, 6.7 inches (17 cm) in diameter, would cause them to close by expansion during a long exposure.

When the jaws of the second slit are of the ordinary form (beveled on the side away from the photographic plate), there is a possibility, as Mr. Evershed has suggested, that light falling on the beveled surfaces may be reflected through the jaws to the plate. In some experiments made during the past summer with a temporary spectroheliograph, the beveled surfaces were turned toward the photographic plate, to eliminate such reflections. In the present instrument a different plan has been adopted. As shown in Fig. 1, which represents the jaws in section, the lower (dead-black) surface is so formed

PLATE VII



The Five Foot Spectroheliograph when under Construction

in steps as to eliminate any possibility of appreciable reflection. In work with narrow dark lines, it is very important that all light be excluded from the plate except that which is due to the line itself. Under such circumstances the above precaution may prove of some value.

To cut off the light from the Sun's disk during an exposure on the chromosphere and prominences, circular metallic screens are provided, and mounted on an adjustable support, as shown in Plate VI. Several of these screens, corresponding to different diameters of the solar image, are available.

In order to give an accurate and rapid means of focusing the solar image on the first slit, a disk can be mounted in front of the slit, as shown in Plate VII. The support that carries this disk can be moved by a rack and pinion, and is provided with a millimeter scale, which defines its position with reference to a fixed mark. A piece of fine white cardboard is mounted on the disk, which is set in rapid rotation. By racking the whirling disk back and forth, the Sun's image (seen through dark glasses) can be very accurately focused on the white surface, which does not show such inequalities of texture as trouble the eye when an image is examined on a stationary surface. When a satisfactory focus is secured, the position of the disk is read on the millimeter scale. The distance from the zero position gives a correction by which the concave mirror of the Snow telescope can be set, with the aid of a millimeter scale attached to the rails on which it slides, so as to bring the solar image exactly in focus on the slit-jaws.

Optical parts.—The collimator and camera objectives, which are of the portrait lens type, were made by the John A. Brashear Co. Their aperture is 8 inches (20.3 cm.), their focal length five feet (152 cm). They seem to meet our specifications in every particular, including sharpness of definition, flatness of field, and equality of focal length. They can be focused from the eye-end, by milled heads, provided with micrometer scales (not visible in the photograph). The tubes, of rectangular section, which unite the first and second slits with the collimator and camera objectives, are provided with a very complete system of diaphragms, which seem to do away with all difficulty from diffuse and reflected light. The tubes of the portrait lenses themselves are also lined with diaphragms, which must

be numerous in order to prevent reflection of light from the ends of the long slits.

On account of the desirability of being able to suit the dispersion employed to the work in hand, the prism-train is so designed that either one, two, three, or four prisms may be used. The prisms are of Jena glass, No. O.102, with faces $8\frac{1}{4}$ inches (21 cm) high and $4\frac{15}{16}$ inches (12.5 cm) wide. The angle of each prism is $63° 29'$. The arrangement of prisms and mirrors ordinarily employed for work with the calcium lines is shown in Fig. 2. When it is desired to obtain a circular image of the Sun, two slits of equal and opposite curvature are used, and the prism-train is arranged to work with one mirror, as indicated by the solid lines in the figure. In this case, as shown by Newall, each point in the solar image will be drawn out

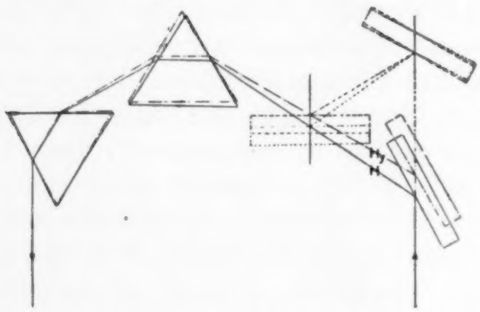


FIG. 2.—Arrangement for Calcium Lines.

in the direction of dispersion into a short line. Under ordinary circumstances the slits are so narrow that the distortion resulting from this cause is entirely negligible. It sometimes happens, however, that important advantages may result (in the case of the H and K lines) from the use of slits so wide that this distortion would be injurious. In such a case, a straight first slit is used with a highly curved second slit, and two mirrors are introduced into the optical train, as shown by the dotted lines. The solar image as a whole will then be distorted, but all of the points in the image will be sharp and well defined. The use of wide slits tends to decrease the contrast, but during the past summer we have obtained excellent photographs of the calcium flocculi and prominences with wide slits, which greatly reduce the exposure time.

In order to bring any part of the spectrum upon the second slit, a mirror immediately in front of the collimator objective can be rotated from the eye-end, by means of a tangent screw. As mentioned above, the final adjustment of the line is made by moving the second slit as a whole. The two prisms are provided with a minimum deviation device, so that they may be brought at once to the position of minimum deviation for any line by setting a pointer at the corresponding reading on a scale. The mirrors may be moved parallel to the optical axis of the collimator, so as to make the light central on the prisms. The position of each mirror is given by a pointer

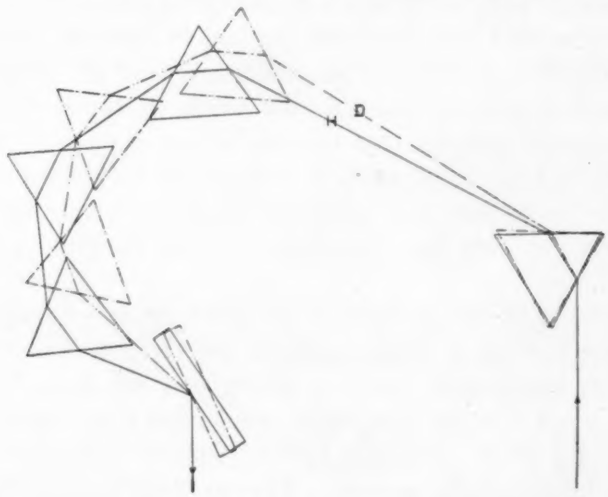


FIG. 3.—Arrangement with Four Prisms.

moving over a millimeter scale. When four prisms are used, the arrangement of the train is as shown in Fig. 3. In this case two mirrors cannot be employed, but they are not needed, since the narrow dark lines used with high dispersion require the use of narrow slits.

Plate-carrier.—As shown in Plate VI, the photographic plate-holder is carried in a light box of cast aluminium, in close contact with the second slit. After the plate-holder has been inserted, the hinged aluminium cover of the box is closed and the slide drawn through a door on the side away from the first slit. This door is then closed and the entire plate-carrier moved forward by rack and pinion until

a conical pin (seen in Plate VI under the iron bracket) drops into a hole in the casting on which the plate-carrier is mounted. In this position the film is almost in contact with the jaws of the second slit.

The plate-carrier is connected with the moving part of the spectroheliograph by a flexible bag, which effectually excludes the light from the plate.

When it is desired to replace the second slit with one of different curvature, the aluminium box can be removed in a moment, by turning the six buttons visible in the photograph.

The driving mechanism.—The moving platform that carries the slits and optical parts of the spectroheliograph is mounted, as already stated, on four steel balls, one inch (2.5 cm) in diameter, running in V-rails. The V's are made of hardened steel, and are ground perfectly true and parallel. As the total weight of the moving parts is approximately 1400 lbs. (636 kg), the system of mercury flotation already referred to was provided to decrease the friction on the steel balls. The result has been extremely satisfactory, the instrument moving with an ease that is surprising when its great weight is considered.

The motion of the platform is produced by either one of two screws, mounted on a strong cast-iron bracket bolted to the iron base. Both screws have hardened and ground end-thrust bearings. The finer screw is of 18 pitch, while the coarser screw, with double thread, is of 3 pitch. The long nuts are split on one side, and can thus be adjusted to take up wear. They are held between the arms of stiff bronze forks, which are connected with the moving platform by steel shafts. The shafts slide freely through cast-iron sleeves bolted to the moving platform. By inserting a conical steel pin, which passes through the sleeve and the shaft, either screw can be made to drive the platform. If neither of the two shafts is fastened to the platform, the instrument can be freely moved across the solar image by hand.

The 1 H.-P. Westinghouse direct-current motor which furnishes the motive power is mounted in a cast-iron frame, shown at the left in Plate VII. By shifting the belt of the motor, any one of three worm gears may be driven by it. Thus either of the screws that move the spectroheliograph may be driven at speeds ranging from 3 to 36

revolutions per minute. The motion is transmitted from the pulleys on the worm-gear shaft to the corresponding pulleys on the heads of the two screws by means of a series of small round belts. Braided fish-line has been found to give more satisfactory results than round leather belting. A single belt of fish-line is sufficient to drive the platform at the highest speed. In practice, however, seven belts of fish-line will be used on each pulley. The driving mechanism is mounted on a pier at some distance below the spectroheliograph,[1] and by moving the idler pulleys shown above the large driving pulleys in Plate VII, the belts corresponding to either the fine-pitch or coarse-pitch screw may be tightened, thus bringing either screw into use.

Current is supplied from a storage battery of 26 cells. The results of the preliminary work indicate that the motion will be very smooth and uniform when all the adjustments have been perfected.

The principal advantages of the new instrument over the Rumford spectroheliograph are: the larger aperture of the collimating and camera objectives, obviating loss of light at the Sun's limb; the possibility of photographing the entire disk with high dispersion; the ease of attaching slits of different curvatures; the possibility of using from one to four prisms, and either one or two mirrors in the optical train; the wide range of speed afforded by the driving mechanism; the elimination of the danger of distortion arising from imperfect synchronism in the motion of solar image and plate; and the ease of manipulation due to the general design and the improvement of details.

RESULTS

The new spectroheliograph, which has been in regular use since October 10, has already yielded some interesting results. On account of the high dispersion of the prisms, and the considerable focal length of the collimator and camera objectives, the $H\delta$ line and the line λ 4045 have been successfully used with two prisms in photographing the hydrogen and iron flocculi. Three photographs of the same region of the Sun, made on November 18, 1905, in quick succession, with the lines λ 4045, H_1 and $H\delta$, are reproduced in Plate VIII. At that time a straight first slit and curved second slit were in use,

[1] In the preliminary work the driving mechanism has been used on a pier north of the spectroheliograph.

and consequently the solar image is distorted. Since the distortion is the same in all three photographs, however, they are strictly comparable with one another. It will be seen that the iron flocculi agree very closely in form with the low-level calcium flocculi. Further remarks on this subject are reserved for a future paper, which will contain the results of comparisons of iron and calcium flocculi now being made with a Zeiss stereocomparator. At present we wish to call attention to the photograph of the hydrogen flocculi, which presents some interesting features.

It will be noticed, in the first place, that the photograph confirms our results obtained with the Rumford spectroheliograph, in showing that most of the hydrogen flocculi are dark, as distinguished from the bright flocculi of calcium and iron. It will also be seen that these dark flocculi correspond roughly in form with the bright flocculi of calcium and iron, though they show certain important divergences. For example, dark flocculi may be found on the hydrogen photograph at points where no bright flocculi appear on the other plates. The H_2 (higher-level) calcium photograph, taken at the same time, also fails to show flocculi at some of these points. These differences in the distribution of hydrogen and calcium in the solar atmosphere will warrant much careful study in the future.

The most interesting feature of the hydrogen photographs, however, which was indicated to a certain extent on some of the plates taken with the Rumford spectroheliograph, is the presence of narrow bright rings, partially or completely encircling certain sun-spots. Fig. 2, Plate VIII, in our paper on the Rumford spectroheliograph, shows a neutral region in the calcium flocculi surrounding the sun-spot; for it cannot be said that this region is materially brighter or darker than the general disk of the Sun in this photograph. In our present plates, however, as may be seen from Fig. 3, Plate VIII (if the reproduction is successful), this region is in some cases distinctly brighter than the general background.

Such rings should be distinguished from the bright eruptive phenomena also frequently shown on hydrogen photographs. The bright eruptions change rapidly in form, whereas these bright rings, which are usually much less brilliant than the eruptions, do not change materially in the course of several hours. They may probably

PLATE VIII

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FIG. 1.—Iron Flocculi.
Slit set on λ4045.

FIG. 2.—Low-Level Calcium, Flocculi.
Slit set on H_1

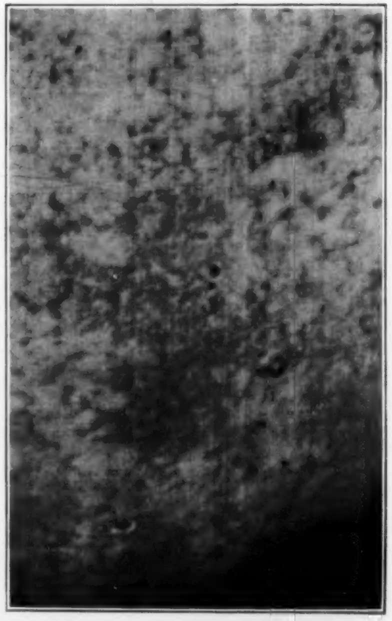

FIG. 3.—Hydrogen Flocculi.
Slit set on $H\delta$.

be taken to indicate the existence of comparatively hot regions in the chromosphere closely encircling certain spots. It will be a matter of great interest to study such regions in connection with other phenomena, such as the radial motion of the calcium vapor, and the intensity of radiation as measured with the bolometer. We have already convinced ourselves that the bright rings are due to hydrogen, and are not caused by any effect on the plate of light from the continuous spectrum of underlying faculæ. Indeed, the faculæ are sometimes faint or absent at the very points where the hydrogen rings are brightest.

Mount Wilson,
December 1905.

LINE STRUCTURE. I.

By P. G. NUTTING

Spectrum lines for use as wave-length standards, or for interference measurements, must possess the simplest possible structure. They must be narrow, invariant, free from satellites, and easily available. At the National Bureau of Standards the investigation of such sources has been undertaken, chiefly with the echelon grating. A general survey of the available spectra produced under various conditions has indicated the limits within which the choice of monochromatic sources must lie. Succeeding papers are to contain more detailed and numerical data on line structure.

The echelon used was made by Petitdidier and contained thirty plates, each fifteen millimeters thick and with half-millimeter steps. Instead of being clamped and mounted vertically in the instrument, they were laid loosely—to avoid strain—in a horizontal position in a carefully planed, rectangular brass trough. Then, with echelon slit horizontal, a spectrum with lines *vertical* was thrown upon the echelon slit by means of an ordinary monochromatic light apparatus. With this arrangement half the visible spectrum may be observed at a single setting, the prismatic dispersion being horizontal, while that due to the echelon is vertical. With the spectroscope slit opened but two or three tenths of a millimeter, the lines of the echelon spectra appear of ample length for observation, and yet the overlapping of echelon spectra is not troublesome, even in working with the iron arc spectrum. With the ordinary arrangement—both slits vertical—a spectral impurity appears as a satellite. With this arrangement the lines due to an impurity appear longitudinally displaced and are easily detected. Again, in comparing lines from a fluctuating source like an arc, it is an advantage to have them simultaneously in the field of view.

The dispersion of the echelon is such that spectra of different order are roughly half a tenth-meter apart in the green; hence line structure could be studied until lines broadened to this width. The separation of lines per given increment of wave-length is approxi-

mately the same (half a millimeter per tenth-meter unit) as for 21-foot concave gratings, while the (calculated) resolving power is about eight times as great. The narrowest lines and satellites observed appeared 0.005 to 0.01 t.-m. broad.

The Fabry-Pérot and Michelson interferometers used for the further study of the "visibility" and structure of some lines were of the ordinary type with planes made by Petitdidier. Fabry[1] suggested interposing a Fabry-Pérot interferometer between the source and slit of a spectrograph, thus obtaining interference bands in all spectrum lines at once. This arrangement was used in some preliminary work in which about forty arc and Plücker tube spectra were photographed. Only the broadest lines, like those of thallium, sodium, and the lead "arc" lines, fail to show interference bands. Even the lines of the sulphur secondary spectrum show them, while with the echelon they show only diffraction bands.

TYPES OF LINE STRUCTURE

A complex spectrum, like that of the iron arc, viewed with the echelon arrangement above described, shows the widest diversity of line structure. Lines are single, double, triple, broad, narrow, or reversed, and are continually changing from one form to another with every fluctuation of the arc. Apparently any line, even those of thallium, hydrogen, or rubidium, which broaden so very easily, may be obtained single and narrow under proper conditions, but hardly one line in ten remains single and narrow when bright enough to be useful for interference work. Some lines simply broaden and reverse without other change in structure, while others double and become very complex before becoming very broad. It appears quite certain that the violet lines are much more easily affected than lines in the red, at least in arc spectra. The green mercury line λ 5461 appears to be quite unique in the possession of its satellites. Of the hundreds of lines examined, not another one has been observed having so complex a structure when so feebly excited.

PLÜCKER TUBE SPECTRA

Rarefied gases moderately excited show narrow lines of the simplest structure, but with a heavy current or capacity in parallel—if the

[1] *Comptes Rendus*, **140**, 848–851, March 27, 1905.

pressure be greater than 3 or 4 mm—lines broaden, and finally, with a spark in series with the tube, widen into a continuous spectrum, with the peculiar fluted appearance characteristic of spark lines. This broadening effect precludes the use of lines of secondary spectra—for example, the bright line spectrum of sulphur—as wave-length standards. Of the twenty-four elements which may be used in Plücker tubes, not more than seven—the helium group, cadmium, and mercury—promise usefulness as monochromatic sources. The lines of the primary spectra of hydrogen, oxygen, nitrogen, sulphur, selenium, tellurium, and the halogens are too faint and too numerous to be available, while the lines of the secondary spectra are too broad. The lines of sodium, potassium, indium, and thallium are far too broad when of sufficient intensity, while the Plücker tube spectra of zinc, phosphorus, arsenic, and antimony are too faint and difficult to obtain to be considered.

The red hydrogen line appears sometimes single and sometimes double, but even when single and vanishingly faint, is 0.1 t.-m. broad. The yellow sodium and green thallium lines may be obtained as narrow as 0.07 t.-m. When a trace of sodium was put in an iron arc, the lines were obtained as narrow as 0.04 t.-m. and fairly sharp. The red helium line at λ 6678 is extremely sharp and narrow, and free from satellites. The bright yellow line, as well as its faint companion, appear rather broad—0.05 t.-m.—but free from satellites and with well defined edges. The appearance of the bright line suggested unresolved components, and an attempt was made to break it up still further with a Fabry-Pérot interferometer, but without success. The line shows excellent visibility over several centimeters difference of path in the Michelson interferometer. The green line λ 5016 and the blue λ 4472 appear single, broad, and sharp, like the brighter yellow line. Other gases of the helium group were not investigated, but there is no reason to suppose that the lines of their spectra would be too broad or too complex for interferometer work.

SPARK SPECTRA

Sparks between metallic electrodes give lines far too broad for use as monochromatic sources. They are never less than half a tenth-meter broad. The effect appears to depend chiefly upon the

amount of capacity used, and is greatly heightened by the use of another spark in series; that is, it is due to the steepness of the wave-front of the current wave. Inductance weakens the wings produced by capacity, and sometimes channels them, but never reduces a line to a simple structure. Occasional lines will appear to simply broaden out under the violence of the discharge, but ordinarily it is simply a case of the dark background—between spectra of different order—becoming luminous.

Using a small current (0.02 amp.) of low voltage (5000) and low frequency (60) and a minimum of capacity, and electrodes of iron and brass, the spark lines were found to be still broad and diffuse. Lines due to impurities (sodium, for example) occasionally appear fairly sharp on but a faint background, but a number of tests indicated that it is impracticable to obtain narrow lines by introducing impurities into the spark.

ARC SPECTRA

Arc spectra are full of bright sharp lines that very rarely show any satellites, but frequently appear double, triple, broad, or reversed, and are constantly varying from one form to another with every fluctuation of the arc. Characteristic structure and variability are exhibited in the sensitive intermediate stage between single narrowness and broad reversal. Every line shows several forms of structure, and many of them run through an extended gamut of forms. The structure which a line exhibits depends primarily upon its intensity; that is, upon the amount of a substance vaporized and the intensity of its excitation in the arc. But in many cases the mere presence of an alien vapor in the arc is sufficient to alter the structure of a line, aside from any effect on its intensity. These latter effects were investigated only in a few cases, the object of this preliminary research being merely to find out the characteristic forms of prominent lines with a view to selecting lines that remain single and narrow when of considerable intensity.

The arc used was one of from two to eight amperes at 120 volts, usually between ordinary arc carbons. When too sluggish in its fluctuations, a graphite rod was substituted for the upper carbon. When a spectrum was too bright, giving lines of too advanced a

structure, it was reduced by adding ammonium chloride or some metal like silver to the arc to ionize it with other than the substance under investigation.

Lithium.—The red line λ 6708, orange λ 6104, and blue λ 4602 were observed. The red and blue lines show continuous broadening, but the orange line shows a pronounced structure, two to five components on a continuous ground. None of the lines was obtained narrow even in an iron arc, ionized with ammonium chloride.

Sodium.—The D lines appear single, double, triple, broad and channeled or continuous, according to the current and the amount of salt in the arc. They are easily obtained single and not over 0.05 t.-m. broad by using a very slight quantity of salt in an iron arc. They go through the same variations in structure; only λ 5890 is always a little ahead of λ 5896, it broadens more, doubles first, its components are more widely separated, and so on.

Potassium.—The red lines are broad and continuous. The group of four lines at λ 580 all show a trace of structure on a continuous ground. The group at $\lambda\lambda$ 535, 510, and 495 showed no trace of structure even in an arc of but half an ampere.

Rubidium.—$\lambda\lambda$ 7811, 6299, 6207, 5724, 5648, 5431, 5436, 4216, 4202 are broad and continuous, the orange group showing a trace of structure, double and triple, on a continuous ground.

Caesium.—The prominent lines $\lambda\lambda$ 6213, 6010, 5845, 4593, 4555 were found to be broad and continuous with no trace of structure.

Magnesium.—The single green line λ 5529 is easily obtained single and narrow in an ordinary arc having one electrode metallic magnesium, but it broadens and doubles easily, and may even become continuous and structureless. Of the green triplet $\lambda\lambda$ 5184, 5173, 5167, the first two are usually obtained with double components 0.07 t.-m. apart, and well defined, while the third is broad and single. With a faint current, or on the edge of the arc flame, or with an arc impregnated with sodium, the double lines appear broad and single, but under the opposite conditions they may be obtained continuous, always retaining some semblance of superposed structure, however. The faint blue (λ 4703) and violet (λ 4352) lines appear single and narrow.

Calcium.—The single red line λ 6719, and the group of red lines at λ 650, appear single and narrow, not over 0.02 t.-m. wide, but with rather diffuse edges. The orange line λ 6162 appears double and λ 6122 single, but both are broad and diffuse. λ 5858 is single and narrow, but diffuse. Other green and blue lines—the 559 group, λ 5350, the 526 group, 5189, the 458 group, λλ 4455 and 4435—appear single and fairly narrow, but the strong violet line λ 4227 appears broad and continuous over a whole order, without a trace of structure.

Strontium.—The strontium spectrum is remarkable for the simplicity and freedom from variation of its lines. While in the iron arc spectrum fully half the lines are double when a heavy current is used, only two, λλ 4832 and 4812, of the forty odd strontium lines are double, and but one, λ 4607, is broad and continuous like the lines of the spectra of the lithium group. In the extreme violet, λλ 4216 and 4078 show a trace of structure, double and triple, on a heavy continuous ground. The green line, λ 4962, widens to about 0.1 t.-m. in a heavy arc, but does not double or reverse. The lines appearing single and narrow, even in a strongly impregnated arc of four amperes, are: λλ 6550, 6503, 6408, 6387, 6161, 6121, the group of eight lines at 55, λ 5330, the group at 525, λλ 5156, 4968, 4962, 4892, the triplet at 487, λλ 4855, 4784, 4756, 4742, 4722, and 4678.

Barium.—The barium lines are more variable and complex than the strontium. Scarcely half of them remain single in a strong arc. Each of the five most prominent lines—the red λ 6497, orange λ 6142, green λ 5536, blue-green λ 4934, and the blue λ 4554—appears broad and continuous with two, three, or five components superposed. The sensitiveness of these lines is remarkable. With every slight fluctuation in the arc they vary from single and narrow to the most complex forms. But all five run through the same series of changes, the same as is run through by the yellow sodium and orange lithium lines under the same conditions, and simultaneously, so far as one can judge. The remaining lines may be roughly divided into two classes: those that double or reverse easily, λλ 6596, 6529, 6482, 6451, 6342, 6111, 6063, 5778, 5519, 5423, and those that remain single in a moderately intense arc, λλ 6695, 6678, 6019, 5997, 5972,

5853, 5826, 4903, 4727, 4691, 4579, 4523, 4432, 4403, 4350, 4283, 4131. It is chiefly a matter of intensity as to which of the three classes a line belongs. All the barium lines appear to be alike in physical structure; that is, they all run through the same gamut of changes of form as their intensity is varied.

Titanium.—All the titanium lines observed, about fifty in the visible region, appear single and narrow. Both the metal and the oxide were used in arcs between electrodes of pure graphite and of ordinary arc carbon, but without obtaining any doubling or reversal effects. Several of the brighter lines appeared to broaden slightly when the arc was intense, but never attained a greater width than 0.08 t.-m. The prominent groups at λλ 450, 500, 520, and 568 are especially striking with the arrangement of apparatus used.

Cerium.—The cerium lines possess the same character as the titanium; they are all single and narrow, even the bright green triplet at λ 519.

Thorium.—All of the numerous thorium lines observed appeared single and narrow.

Vanadium.—Except the group of blue lines at λ 440, all the vanadium lines appear single and sharp. Six prominent lines of this blue group appear double, but they do not vary in structure with the fluctuations of the arc and could not be obtained single at the limit of visibility.

Chromium.—Half a dozen of the strongest chromium lines twin or reverse in strongly impregnated arcs, carrying a heavy current. The remaining lines are single and narrow. The lines of the green triplet λλ 5204, 5206, 5208, are the most variable of all. Other lines showing variable structure are λ 4666, the group at λ 454, and the strong violet lines at λ 43.

Molybdenum.—The numerous orange, yellow, and violet lines are single and narrow; the whole spectrum, in fact, except two—λλ 5532 and 5506—of the prominent green triplet. All lines, however, show a tendency to broaden and reverse as the arc flashes out strongly, and for variability the spectrum should be classed just under that of iron.

Tungsten.—No tungsten lines were observed to double or reverse in an arc of four amperes between carbon electrodes fed with metallic tungsten. A few of the brighter red and green lines appear to broaden slightly.

Uranium.—The lines of the uranium spectrum are so excessively numerous and so uniform in intensity that they appear as a continuous spectrum, with perhaps fifty of the more prominent lines superposed. None of the lines shows either doubling or other changes of structure.

Manganese.—The manganese spectrum is a very interesting one, the lines showing a wide diversity in structure and variability. Two bright blue lines, λλ 4823 and 4783, broaden and reverse with each flash of the arc. The lines of the strong orange triplet, λλ 6022, 6017, 6014, are wide (0.10 t.-m.), but do not double or reverse. The two groups of bright lines in the violet, at λ 445 and λ 405, remain single and invariant, as do all the fainter lines throughout the spectrum.

Iron.—The iron lines, like the barium lines, appear to be all of the same character as regards variability. The general gamut of changes which a line goes through as its intensity is increased is as follows: Lines appear of a minimum width of 0.02 t.-m. when first visible; as the line becomes stronger it broadens uniformly, remaining sharp on its edges, to about 0.045 t.-m., when it divides sharply through the center. These twin lines then move apart, each retaining its original narrowness and sharpness of edge, until separated by a sharp dark space, 0.03 to 0.07 t.-m. broad. Then, and not until then, do the twin lines themselves broaden, blur at the edges, and fill in the intermediate dark channels. This last effect is the reversal proper. With an arc of 3 amperes between iron electrodes, eight or more of the strongest lines, λλ 5328, 5270, 4957, 4921, 4384, 4326, 4308, 4271, appear in the twin stage, all others single. At seven amperes these strongest lines are just reaching the last stage of reversal proper, and about thirty of the next strongest lines have twinned. As the arc sputters and flashes out, the stronger lines may be seen to go through the whole series of changes in a fraction of a second.

Cobalt.—Of the cobalt spectrum the same may be said as of the iron spectrum; all lines appear to be alike in character—i. e., they all run through the same gamut of changes—the spectrum of a line depending upon its intensity alone. Here again the violet end appears to be slightly more variable than the red end, but the effect is not greater than might be due to the difference in photometric sensitiveness of the eye.

Nickel.—The nickel spectrum behaves like the spectra of iron and cobalt. The prominent green line λ 5477 is the first visible line to reverse. This and other lines, in reversing, appear to broaden more, with less sharply defined edges than iron lines.

Rhodium closely resembles iron in the character and behavior of its lines. Lines twin (see especially λ 5422 and λ 4375), remaining sharp before reversal proper occurs.

Palladium is more like nickel, the lines broadening with diffuse edges before reversal.

Osmium and *platinum* behave like their chemical neighbors. Half a dozen of the stronger lines of each may easily be obtained doubled and reversed in the flashes of an arc, the upper electrode of which is graphite.

Copper.—Copper lines differ widely in structure and behavior. λ 5782 is nearly always double, while λ 5104, of about equal intensity, never doubles; diffuse lines like λ 4587 show not a trace of structure at any intensity, while other lines, like λ 4651, remain persistently single and narrow. The line λ 5782 twins abruptly when very faint and remains with components sharp and at a constant distance (0.07 t.-m.) apart until just as it breaks down in the reversal proper. Just as this occurs, each of the two components appears to double, but the transition is very rapid and just at the limit of the resolving power of the echelon. λ 5700 triples when faint, and changes only in intensity until it breaks down in complete reversal. The new components appear at distances 0.02 t.-m. from the primary, are about one-fifth as bright and are rather diffuse. But each of these lines may appear with quite different structure. In working with silver, copper was fed into the arc to reduce the silver lines. Then

Cu λ 5700 appeared sharply twinned instead of triple, while λ 5782 was triple with sharp and well-separated components. In a brass arc both lines appeared double, with just a suggestion of a hazy third component in the brighter flashes of the arc. Finally, a brass- or copper-fed carbon arc gave the structures originally described, λ 5782 double, λ 5700 diffusely triple, which the addition of silver changed, first to both lines triple, and then to λ 5700 double and λ 5782 triple. The green group, λλ 5218, 5153, and 5106, is much more sensitive to fluctuations in the arc than the yellow pair. These green lines widen out with diffuse edges until they reverse. When reversed, they show a trace of structure, usually two, occasionally three, components appearing on a continuous ground. The faint companions of λ 5218 appear at first glance as satellites of that line, but may easily be distinguished by their longitudinal displacement. The violet lines are either too diffuse to show structure, or else they behave like the green group.

Silver.—The bright green pair, λλ 5465 and 5209, are alike in structure and behavior. They may be obtained single, but never with sharp edges, from the outer edge of the arc flame, or by filling the arc with some other metal, like copper. In reversing, they first triple, ill-defined components appearing on either side of the primary at a distance of 0.06 t.-m., and of about one-fourth its intensity. Finally, as the line breaks down into a continuous blaze, five components appear superposed upon the continuous background. However, the central primary component remains always the brightest of them all, instead of dropping out as in the case of the yellow copper lines. The blue pair, λλ 4669 and 4476, and the violet pair, λλ 4212 and 4055, appear to be of the same character and behavior as the green pair. They triple as they broaden, and finally reach a five-component stage with bright primary.

Gold.—All of the five prominent gold lines, λλ 6278, 5838, 5230, 5064, 4793, appear single and fairly narrow, in the spectrum from a gold-fed carbon arc, but with extremely diffuse edges. These gold lines exhibit the most gradual falling off of intensity from the center outward of any of the lines observed. They broaden very easily, but show no trace of structure, nor do they reverse in an arc of eight amperes, so intense as to vaporize the gold very rapidly. The

reversal appears to be of the simplest type, a mere broadening and division.

Zinc.—All four zinc lines are rather diffuse, and are usually found double or triple. The blue group of three lines closely resembles in character and behavior the analogous green copper group. The red zinc line λ 6363 is obtained single only when extremely faint. It is usually triple, with diffuse components separated by about 0.08 t.-m. from the central primary, the companion of lesser wave-length being about half as bright as the primary and four times as bright as the companion of greater wave-length. The blue lines, $\lambda\lambda$ 4810, 4722, 4680, are broad and diffuse, and show a trace of structure on reversal.

Cadmium.—The cadmium lines do not differ greatly from the lines of zinc in character and behavior. The red line λ 6438 doubles when very faint, remains double over a wide range of intensity, then breaks down into a continuous blaze that shows a trace of five superposed components. The green, blue, and violet lines triple while faint, with broad, diffuse companions, which soon increase to cover a whole order. When the arc was reduced with silver or copper, these lines appeared to broaden directly without breaking up. Occasionally the green line flashed out double instead of triple, the third component, the companion of greater wave-length, being lacking.

Mercury.—Mercury lines broaden and reverse, showing a decided structure very like the lines of the related zinc and cadmium. By reducing the arc with silver or copper, the mercury lines were obtained in the intermediate stages, showing the structure obtained when the source is a Plücker tube. Yellow λ 5790 appeared with four components: —0.11, 0.0, +0.13, and +0.23 t.-m. Yellow λ 3769 appeared triple, the faint companion being at a distance of 0.03 t.-m. on either side of the primary. Green λ 5461 was obtained with the well-known three and five satellite structure which in the arc easily goes over into a broad continuous blaze. Blue λ 4358 appeared in the intermediate stage with three satellites: −0.16, +0.04, and +0.20 t.-m.

Indium.—The blue line is double, with broad and diffuse com-

ponents in the intermediate stage, but easily goes over into a continuous blaze in an arc of three amperes.

Thallium.—The strong green thallium line, λ 5350, is so broad and diffuse that it is difficult to obtain it single in an arc in open air. The line was reduced to a simple double form by adding a large excess of silver to the arc, but remained double down to the limit of visibility. The components are diffuse, are separated by a distance—constant over a wide range of intensity—of 0.11 between centers, and are of decidedly unequal intensity, the component of lesser wave-length being fully three times as intense as the other. As the intensity increases, the fainter component overtakes its companion in brightness, becomes much brighter, and then itself becomes double just as the line goes over into its final stage, exceeding several orders of echelon spectra in width. Using a brass arc, with a small quantity of thallium added, at one stage, strong, well-defined triplets were obtained about 0.09 t.-m. apart. The middle component of this triplet danced about from side to side in the liveliest manner. As the arc flashes up, it attaches itself to the outer component of greater wave-length; as the arc dies down, it leaps to the opposite side, joins with the component of lesser wave-length, and the structure reduces to the doublet first described.

Tin.—The green line λ 5631 and the blue λ 4525 are alike in structure and behavior. When single they are narrow, but with very diffuse edges. As their intensity is increased, they broaden much more rapidly on the side of lesser wave-length, and finally a diffuse component splits off on this side, just as the lines go over into complete reversal.

Lead.—In an ordinary arc of say three amperes, the orange line λ 6002 and the violet λ 4058 appear extremely broad and diffuse with a trace of structure—two or three components—superposed, while the green lines λλ 5201 and 5005 are single and narrow, but with diffuse edges. With an arc of four amperes, the green lines advance to the diffuse structure of the orange and violet lines described above. With a current of two amperes, and with an excess of silver to reduce the lead spectrum, λλ 6002 and 4058 are reduced to a single narrow structure with diffuse edges.

Of the remaining metallic elements, beryllium, boron, aluminium, carbon, silicon, phosphorus, arsenic, and antimony give no arc lines of sufficient intensity in the visible spectrum, while a number of the very rare elements were not available.

An inclosed arc, provided with brass electrodes, was used at low pressures and filled with hydrogen. The substitution of hydrogen for air as an atmosphere was without noticeable effect, even on the sensitive copper lines $\lambda\lambda$ 3700 and 5782. At low pressures all single lines and all the components of double and triple lines appear much narrower and sharper than at atmospheric pressure. But the removal of the atmosphere appears to be without other influence on the structure of lines; λ 5700 is triple, and λ 5782 usually double, occasionally triple as at ordinary pressures.

DISCUSSION

Perhaps the most striking feature of line structure, in contrast with spectral structure, is its variability. The components and satellites of a line vary constantly in number, relative intensity, and position with every slight fluctuation of the source, and often indeed without any apparent cause whatever. And since every line may appear in any one of several forms, we may hardly speak of any line as having a fixed definite structure, even with a minute specification of conditions of production.

A classification of the various structures exhibited by different lines under varied conditions leads to a grouping under a few prominent types.

(*a*) Lines accompanied by faint companions or satellites of the nature of distinct spectrum lines. The yellow helium line is typical, also the green mercury line. Lines of this type are never obtained single, and are but little, if any affected in structure by causes producing a change in intensity.

(*b*) Lines that, originally single and simple in structure, with increasing intensity merely broaden indefinitely, or broaden and reverse in simple reversal if the source is such that absorption phenomena may take place. Many prominent lines are of this type, those of gold being characteristic.

(*c*) Lines that in the intermediate stage twin, with sharp, widely

separated components that recede steadily from each other as the intensity of the source is increased. This structure and behavior are exhibited by the lines of the spectra of iron, platinum, and many related metals. This effect is by no means to be confused with the apparent doubling of (*b*), the ordinary reversal effect; it resembles more the Zeeman effect in its wide, sharp separation occurring abruptly as the intensity is increased.

(*d*) Lines that are triple in the intermediate stage. The single lines first develop wings. These wings detach themselves from the primary, and increase in brightness so much more rapidly than the primary that finally the center of the complex line is relatively dark; ordinary reversal appears to have taken place. All lines which triple symmetrically, so far as I know, reverse in this manner.

(*e*) This is a miscellaneous class, comprising a few lines which broaden, double, or triple unsymmetrically. Single lines sometimes develop unsymmetrical wings, the brighter one being the first to detach itself. Or, in ordinary reversal, a line may divide at one side of the center, the stronger component later subdividing, giving the line a triple structure at one stage. The green thallium line is characteristic of this class.

The phenomena attending reversal have as yet been by no means clearly worked out, and will require much further study; but even from the effects here described it is difficult to see how the old absorption theory can account for types (*c*), (*d*), and (*e*) above. An explanation of these effects appears to require a consideration of the varying modes of vibration of the primal radiators as a function of the intensity of excitation. For instance, in class (*c*), where lines double sharply with receding components, it is not difficult to imagine a radiating system that would give twin, complementary, variable periods when strongly excited; and would not the assumption of elliptical orbits account for the apparent vagaries of unsymmetrical broadening, doubling, and tripling of type (*e*)?

Some relations between line structure and spectral structure may be pointed out. All the lines in those spectra—iron, uranium, and barium, for example—for which no series relations are known, are alike in structure and behavior, the observed structure at any time being a function of the intensity alone. Where series relations are

known, lines of the same spectral series behave alike, but often quite differently from lines in another series. Lines occurring in pairs with constant frequency difference are alike in structure and behavior in each pair, and usually in all the pairs of the spectrum.

The selection of lines and spectra for use (1) as standard wave-lengths, (2) as absolute length standards, and (3) as sources in interferometry, can be made only when both structure and behavior are taken into account. The chief general requirement of importance in this connection is that such line or lines must remain single and narrow, as the intensity is varied over a wide range. Lines must then be selected entirely from class (*b*) above; and there are abundance of arc lines, and indeed whole spectra, in which lines remain single and narrow when of ample intensity for the most light-wasteful interferometry.

BUREAU OF STANDARDS,
Washington, D. C.
November 1905.

PHOTOGRAPHIC PHOTOMETRY OF SHORT-PERIOD VARIABLE STARS

By J. A. PARKHURST and F. C. JORDAN

During the past two months some investigations have been carried on at this Observatory to determine photographically the light-curves of several stars known or suspected to be variables of very short period. The instrument used was the 24-inch reflector. The plates were Cramer Crown, Cramer Isochromatic, and Seed 27, most of the work having been done with the last named. The method was as follows: During a time either partially or wholly covering the star's period, exposures were made at short intervals on the same plate, the images being separated by moving the plate slightly between exposures. As the double-slide plate-holder was used, the plate could be moved while leaving the star in the same position in relation to the optical axis of the telescope, thus introducing no differential distortion of the star image. The diameters of the images were measured in both right ascension and declination, and from the means the magnitudes were calculated by Charlier's formula, $m=a-b \log D$, which seems to fit most nearly the instrument and Seed plates. For the Cramer Crown, the formula $m=a-bD^{0.9}$ seems better. The exposures were so timed as to give fully blackened images of the faintest stars needed without over-exposing the brighter stars. Details will be given in the discussion of each star. It seems probable that star magnitudes can be determined from the photographic images with a little greater accuracy than by visual methods; at any rate, the photographic method has two important advantages: first, the plate is free from certain systematic errors which seem inherent in visual work; second, any doubtful measures may be repeated at will.

It is thought that the present work possesses three advantages over some previous photographic determinations of magnitude: (1) the excellent definition of the reflector images makes it possible to measure the diameters with considerable accuracy; (2) the measures were made to 0.001 mm under the microscope, instead of com-

paring the images with a scale-plate; this may be said to replace estimates with measures; (3) the great speed of photographic action of the reflector makes it possible to extend the work to faint stars without requiring an exposure which would cover a considerable portion of the star's period, thus avoiding the danger of smoothing out the light-curve. The longest exposures relative to the period of variation were on the variable 14.1904 *Cygni*, six minutes, where the period is three hours, thus using only one-thirtieth of the period.

Announcements have been made lately of a number of variables of very short period, which would be of great interest and importance if the variation proves real. The conflict of opinion in some of these cases between the most careful and skilful observers is very puzzling to the astronomical world, so that any independent method of checking the reality of the variation would be welcome even if it was no more accurate than the visual methods. But if at the same time there is a slight gain in accuracy, the importance is obvious. To test the matter we offer measures of the following stars:

1. The *Algol*-type variable *U Cephei*, the light-curve of which is well determined. (Compare, for example, Yendell's article in the *Astronomical Journal*, **23**, 213, 1903.)

2. The short-period variable *W Ursae Majoris*, which has been carefully investigated visually by Müller and Kempf, who have given details in the *Astrophysical Journal*, **17**, 201, 1903.

3. The new variable 14.1904 *Cygni*, announced by Ceraski in *Astronomische Nachrichten*, **165**, 61, 1904, but not yet confirmed, as far as known to the writers.

4. Barr's variable *32 Cassiopeiae*,[1] which has the provisional number 186.1904, and which has been confirmed visually by Yendell and Hartwig.

The agreement of our results for the first two stars with the well-determined curves will enable the reader to form an independent judgment of the confidence which can be reposed in the confirmation of Ceraski's star and the failure to confirm Barr's variable.

U CEPHEI

The measures were made on plate No. 71 taken with 18 inches aperture on the 24-inch reflector on June 25, 1904, from $9^h\ 11^m$ to $14^h\ 51^m$ Central Standard Time. There were twenty exposures

[1] R U Cassiopeiae in *A. N.* **170**, 69, 1905.

made on the plate, ranging from 1^m when the variable was bright, to 3^m when it was near minimum. The plate was moved half a turn of the declination screw of the double-slide holder between each exposure, except that for aid in identification a whole turn was made after each fifth exposure, and the last exposure was made by a motion in right ascension. Seeing good, bright moon. The diameters of the star images were measured to 0.001mm with the small Gaertner machine, in an east-and-west direction; the mean of Jordan's and Parkhurst's measures were used. The formula used in the reductions was

$$\text{Magnitude}=a-bD^{0.9},$$

in which a and b are constants and D is the diameter expressed in thousandths of a millimeter. The exponent of D, 0.9, was found by trial. The following comparison stars were used, the letter and Potsdam photometric magnitude being taken from Yendell's paper in the *Astronomical Journal*, **23**, 213, 1903:

Star	*B.-D.*	Magnitudes	
		Potsdam	Photographic
j	81°30	8.04	8.04
g	81.27	8.53	8.73
d	81.22	9.29	9.29

The photographic magnitude of *g* was deduced from the measures, using *j* and *d* as standards.

TABLE I.

320 U CEPHEI

Plate 71, 1904, June 25

G. M. T.	Mag.	Residual	G. M. T.	Mag.	Residual
15 12.0	8.00	0.00	19 19.6	9.10	+0.01
15 43.4	8.17	+0.03	19 45.6	8.95	+0.01
16 00.9	8.22	−0.04	20 04.4	8.74	−0.05
16 20.5	8.34	−0.12	20 16.3	8.68	−0.01
16 37.6	8.72	+0.06	20 28.2	8.52	−0.04
16 59.8	8.84	−0.04	20 36.0	8.44	−0.04
17 20.8	9.10	+0.06	20 44.0	8.38	−0.01
17 39.7	9.18	+0.04	20 50.0	8.36	+0.03
18 02.7	9.15	−0.07			
18 19.2	9.26	+0.03			
18 50±	9.12	−0.07	Mean	±0.04 mag.	

Table I shows the results of the measures, the last column giving

the residuals from the smooth curve shown in Fig. 1. The average residual, ± 0.04 magnitude, compares favorably with the best visual measures.

The light-curve yields the following results:

Minimum 1904, June 25, $12^h\ 20^m.0$ Central Standard Time
Reduction to Sun $-3^m.5$
Heliocentric minimum, $12^h\ 16^m.5$ Central Standard Time
or 1904, June 25, $18^h\ 16^m.5$ Greenwich Mean Time
Magnitude at minimum 9.23

W URSAE MAJORIS

This star, *B.D.* $+56^\circ.1400$ (R.A. $9^h\ 36^m\ 44^s$, Dec. $+56^\circ\ 2'.46$, 1900), discovered by Müller and Kempf in the course of their photometric work, is a well-known variable of very short period, a few seconds more than four hours. Three plates have been taken here with the 24-inch reflector, having in all thirty-five exposures. The following comparison stars have been used:

Star	*B.D.*	Mag.	Photog. Mag.	R. A. (1855)	Dec. (1855)
a............	$56^\circ.1397$	6.5	6.72	$9^h\ 31^m\ 3^s.5$	$+56^\circ\ 31'.1$
b............	56.1398	9.0	8.68	9 32 13	+56 50.5
c............	56.1399	8.5	8.61	9 32 27.5	+56 19.5

Details of exposures and calculated magnitudes are given in the table below:

TABLE II

Exp.	Plate 272, Nov. 9, 1905		Plate 326, Dec. 7, 1905		Plate 327, Dec. 7, 1905	
	G. M. T.	Mag.	G. M. T.	Mag.	G. M. T.	Mag.
1.......	$19^h\ 15^m$	8.17	$18^h\ 00^m$	7.32	$20^h\ 00^m$	7.86
2.......	19 31	7.53	18 15	7.36	20 7½	7.83
3.......	20 44	7.54	18 30	7.30	20 15	7.86
4.......	21 05	7.35	18 45	7.43	20 22½	7.61
5.......	21 20	7.25	19 00	7.56	20 30	7.61
6.......	21 35	7.33	19 7½	7.43	20 37½	7.59
7.......	21 53	7.30	19 15	7.37	20 45	7.57
8.......	22 10	7.24	19 22½	7.32	20 52½	7.47
9.......	22 25	7.48	19 30	7.44	21 00	7.52
10.......	22 40	7.58	19 37½	7.37	21 15	7.32
11.......	22 59	7.91	19 45	7.54	21 30	7.45
12.......	23 20	7.95	19 52½	7.56		
Seeing	fair		very poor		poor	

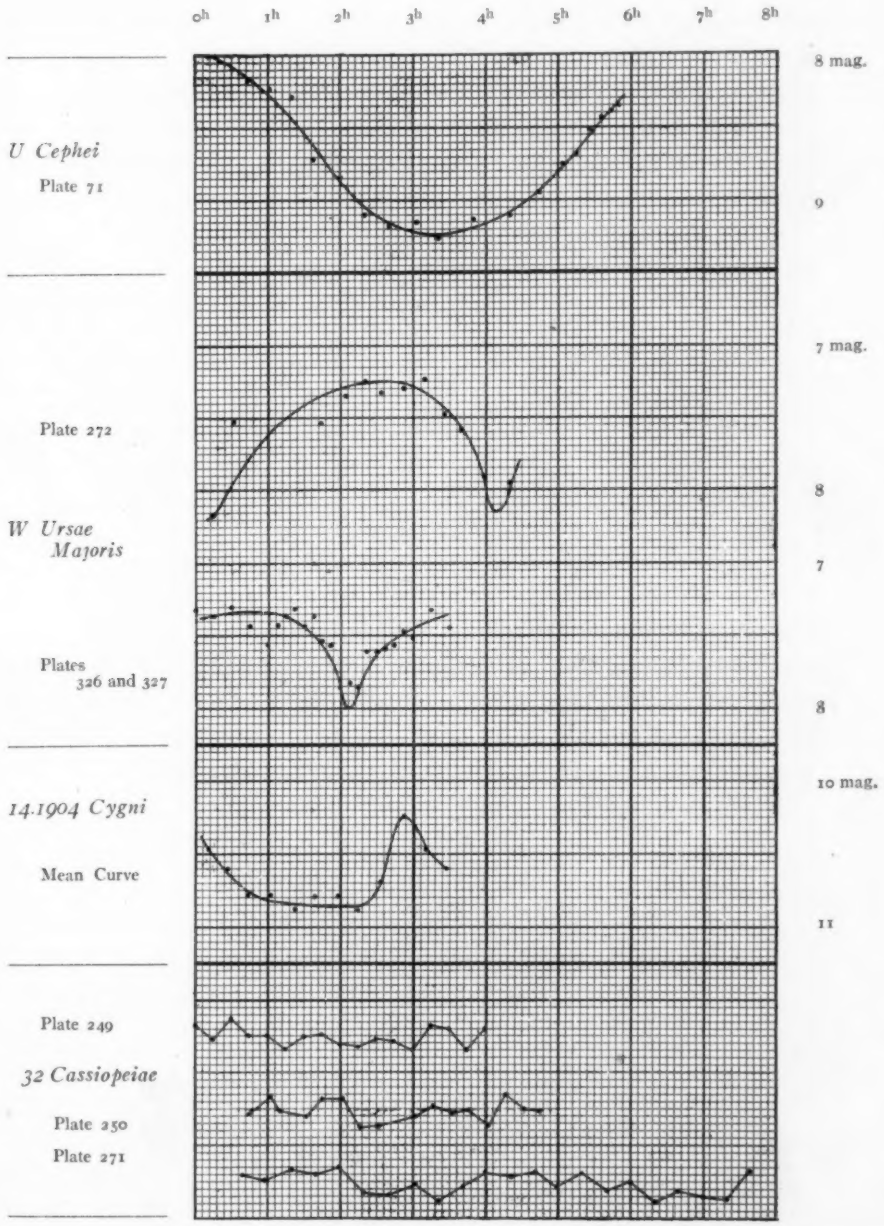

Fig. 1.—Light-Curves.

The interval between exposures 2 and 3 of Plate 272 was caused by a sudden clouding of the sky. Plates 326 and 327 were taken under very unfavorable conditions, because of extreme unsteadiness of seeing; therefore the results from those plates cannot be given the same weight as from Plate 272. Nevertheless, they show the sharp minimum and flat maximum as in Fig. 1, corresponding very closely with the curve obtained by Müller and Kempf from a long series of visual observations.

The comparison with minima calculated from Müller and Kempf's data given in *A.N.*, **167**, 347, 1905, follows:

E	Observed	Red. to Sun	Heliocentric Minimum	Calculated	Residual
1777	1905, Nov. 9, 19^h 15^m	$+1^m.3$	19^h 16^m	19^h 18^m	$+2^m$
1945	1905, Dec. 7, 20^h 7^m	$+4.0$	20 11	19 58	$+13$

14. 1904 *CYGNI*

R. A. 20^h 1^m $18^s.46$, Dec. $+58°$ $40'$ $16''.9$ (1900)

This variable was announced by Ceraski in the *Astronomische Nachrichten*, **165**, 61, 1904, with the statement that the range was from 10.7 to 11.6 magnitude, the period about 3.2 hours, and the light-curve resembling the "cluster variables." Our observations confirm the range and the shape of the curve, but are better satisfied by a somewhat shorter period, 3^h 1^m 264^s (0.126 day).

The plates taken are listed in Table III.

TABLE III

Number	Date 1905	G. M. T.		No. of Exposures	Seeing
		From	To		
300..........	Nov. 21	13^h 27^m	13^h 40^m	2	good
306..........	22	11 35	15 30	16	unsteady
307..........	22	15 33	15 39	1	unsteady, low
313..........	25	12 16	13 41	8	very poor
314..........	26	11 46	13 41	12	good
315..........	26	13 46	15 12	9	good
318..........	28	12 50	13 10	1	good
319..........	28	13 12	13 48	1	good

The positions of the variable and the comparison stars given in Table IV were measured on Plate 318, based on the *A. G.* Catalogue places of the stars *a*, *b*, and *e*. The position of the variable for 1900

was found as given above; the other stars can be located by means of the co-ordinates from the variable given in the table, and also from the chart, Fig. 2.

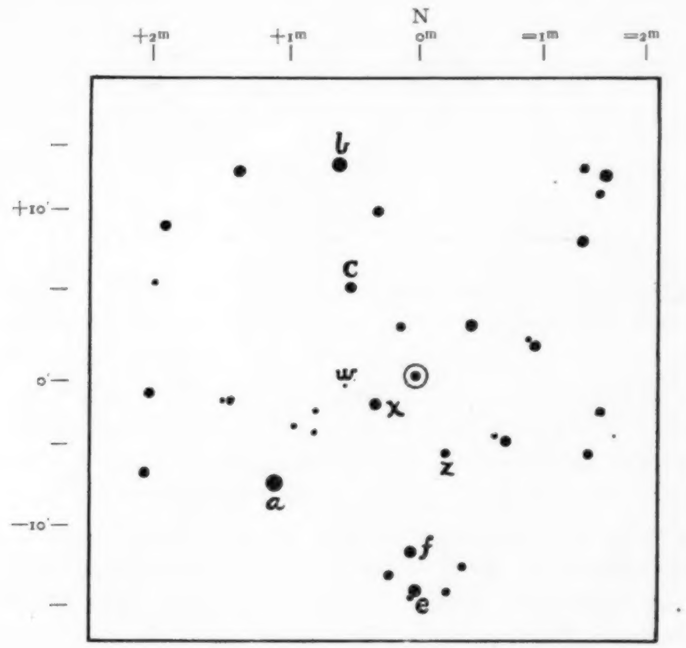

FIG. 2. 14.1904 *Cygni*.
R. A. $20^h\ 1^m\ 18^s.46$, Dec. $+58°\ 40'\ 16'.9$ (1900)

TABLE IV

	B.-D.	Co-ordinates from Variable			Mag.	
		R. A.		Dec.	Photom.	Photog.
z.........	....	$-127'.8$	$-16^s.38$	$-293'.8$	11.02	.....
e.........	58°.2040	− 27.7	− 3.52	−824.6	.....	.....
x.........	....	+153.2	+19.58	−119.7	10.12	9.99
c.........	*58.2043	+265.5	+33.98	+323.9	10.00	10.14
w.........	....	+270.6	+34.69	− 50.1	12.1 ±	.....
b.........	58.2044	+335.2	+43.23	+794.2	9.26	9.25
a.........	58.2046	+520.9	+66.53	−441.2	8.66	9.06

It was found by trial that the observations were best satisfied by a period of 0.126 day ($3^h\ 1^m\ 26^s.4$), so that the following ephemeris of maximum was calculated:

TABLE V

Epoch	Calculated		Observed
	J. D.	Calendar	
−9	7171.469	Nov. 21, 11^h 16^m	......
−1	7172.477	22, 11 38	......
0	7172.603	22, 14 28	14^h 25^m
23	7175.501	25, 12 2	no max.
31	7176.509	26, 12 13	12 00
46	7178.399	28, 9 35	......
47	7178.525	28, 12 36	12 52
102	7185.455	Dec. 5, 10 56	......
103	7185.581	5, 13 57	13 00

By the aid of this ephemeris, the observed magnitudes given in Table VI were grouped into ten normal points, giving the mean light-curve shown in Fig. 1. Table VI gives the current number, the plate and exposure number, the Greenwich Mean Time, both calendar and Julian, the epoch number, ΔT, the time elapsed since the preceding maximum, the measured magnitude, and the residuals from the mean curve. The photometric magnitudes were found by the equalizing wedge photometer used on the 12-inch refractor, using as standards the stars in the field of 7220 *S Cygni*, one degree south. From the photometric magnitudes of the stars *b*, *c*, and *x*, the constant *b* in the reduction formula came out smaller than usual, thus giving a range for the variable of 0.52 magnitude. If the usual value of *b* were used, the range would be larger, about 0.77 magnitude, agreeing better with the range given by Ceraski. Table VI also contains seventeen measures with the wedge photometer, distinguished by the abbreviation "vis." in the second column in place of the plate number. The photometric magnitudes have been decreased numerically by 0.40, then giving results closely accordant with the photographic, both as to magnitude and shape of the light-curve.

While the separate light-curves agree well in shape, a consideration of the residual column gives the impression that the period is not quite constant, the preponderance in sign being such that it cannot be improved by change either in length of period or in the zero epoch. For this reason the residuals include both the accidental errors of the measures and the effect of apparent change of period. Further

observations will be required to settle the question of the regularity of the change; but if this confirmation is accepted, the star will enjoy the distinction of possessing the shortest known period.

TABLE VI

MAGNITUDES AND RESIDUALS

No.	Plate	Date. G. M. T. Calendar			J. D.	E	Δ *T*	Mag.	Residual
		1905	h	m					
1.....	300, 1	Nov. 21	13	32	7171.564	−9	0.095	.....	......
2.....	2	21	13	39	71.569		0.100	.....	......
3.....	306, 1	22	11	38	72.485	−1	0.008	10.50	−0.03
4.....	2		11	53	72.495		0.018	10.66	−0.08
5.....	3		12	07	72.505		0.028	10.82	−0.14
6.....	4		12	23	72.516		0.039	10.77	−0.03
7.....	5		12	38	72.526		0.049	10.98	−0.17
8.....	6		12	56	72.539		0.062	10.93	−0.09
9.....	7		13	06	72.546		0.069	10.97	−0.12
10.....	8		13	26	72.560		0.083	11.03	−0.18
11.....	9		13	39	72.569		0.092	11.13	−0.30
12.....	10		13	53	72.578		0.101	10.92	−0.15
13.....	11		14	08	72.589		0.112	10.23	+0.28
14.....	12		14	25	72.598		0.121	10.36	−0.01
15.....	13		14	38	72.610	0	0.007	10.35	+0.11
16.....	14		14	54	72.620		0.017	10.58	−0.00
17.....	15		15	08	72.631		0.028	10.89	−0.20
18.....	306, 16		15	26	72.643		0.040	10.78	−0.00
19.....	307, 1	Nov. 22	15	36	72.650		0.047	10.94	−0.13
20.....	313, 1	25	12	19	75.513	23	0.012	10.53	−0.02
21.....	2		12	30	75.520		0.019	10.62	−0.02
22.....	3		12	40	75.528		0.027	10.69	−0.01
23.....	4		12	50	75.535		0.034	10.63	+0.10
24.....	5		13	00	75.542		0.041	10.75	+0.03
25.....	6		13	13	75.550		0.049	10.48	+0.34
26.....	7		13	26	75.560		0.059	10.19	+0.65?
27.....	8		13	38	75.568		0.067	10.20?	+0.66?
28.....	314, 1	Nov. 26	11	47	76.491	30	0.108	11.76	−0.13
29.....	2		11	58	76.499		0.116	10.32	+0.09
30.....	3		12	08	76.506		0.123	10.34	−0.02
31.....	4		12	18	76.513	31	0.004	10.45	+0.02
32.....	5		12	28	76.519		0.010	10.54	−0.05
33.....	6		12	38	76.526		0.017	10.49	+0.08
34.....	7		12	48	76.533		0.024	10.68	−0.03
35.....	8		12	58	76.540		0.031	10.75	−0.04
36.....	9		13	08	76.547		0.038	10.75	+0.01
37.....	10		13	18	7176.554		0.045	10.79	+0.01

TABLE VI—*Continued*

No.	Plate	Date. G. M. T. Calendar			Date. G. M. T. J. D.	E	Δ T	Mag.	Residual
		1905	h	m					
38.....	11	Nov. 26	13	28	7176.561		0.052	10.85	−0.02
39.....	12		13	38	76.568		0.059	10.86	−0.02
40.....	315, 13		13	48	76.575		0.066	10.66	+0.19
41.....	14		13	58	76.582		0.073	10.75	+0.10
42.....	15		14	08	76.589	31	0.080	10.69	+0.16
43.....	16		14	18	76.596	31	0.087	10.65	+0.20
44.....	17		14	28	76.603		0.094	10.64	+0.18
45.....	18		14	38	76.610		0.101	10.79	−0.02
46.....	19		14	48	76.617		0.108	10.73	−0.10
47.....	20		14	58	76.624		0.115	10.80	−0.36
48.....	315, 21		15	08	76.631	31	0.122	10.36	−0.01
49.....	vis.	Nov. 28	11	52	78.494	46	0.095	10.84	+0.02
50.....			12	06	78.504		0.105	10.85	−0.14
51.....			12	18	78.513		0.114	10.63	−0.18
52.....			12	31	78.522		0.123	10.55	−0.19
53.....			12	39	78.527	47	0.002	10.36	+0.05
54.....			12	50	78.535		0.010	10.31	+0.13
55.....			12	57	78.540		0.015	10.46	+0.09
56.....	318, 1		13	00	78.542		0.117	10.37	−0.20
57.....	vis.		13	09	78.548	47	0.023	10.37	+0.27
58.....			13	27	78.560		0.035	10.52	+0.22
59.....	319, 1		13	30	78.562		0.037	10.59	+0.16
60.....	vis.		13	47	78.574		0.049	10.59	+0.22
61.....			14	12	78.592		0.067	10.69	+0.26
62.....			14	36	78.608		0.083	10.86	0.00
63.....			15	11	78.633		0.108	11.3?	−0.7 ?
64.....	vis.	Dec. 5	13	25	85.559	102	0.104	10.46	+0.27
65.....			13	41	85.570		0.115	10.49	−0.06
66.....			14	34	85.607	103	0.026	10.74	−0.07
67.....			14	48	7185.617		0.036	10.74	0.00

32 CASSIOPEIAE

B. D. +64° 127 = *Hels.-Gotha A. G.* Cat. 983, $1^h\ 5^m\ 10^s.14$, +64° 29′ 12″.7, 1900

This star was announced as variable by Barr in the *Astronomical Journal*, **24**, 145, 1904, where the period was given as nearly eight hours and the range 0.4 magnitude. The light-curve given is of unusual shape, the rise and fall being nearly vertical. The variation was confirmed by Yendell in the same *Journal*, page 173, but he found the curve of the usual short-period type, without halt either at maximum or minimum. An added confirmation is given by Hartwig in the *Vierteljahrsschrift*, **40**, 94, 1905, with the statement that the change

is rapid and the maxima and minima can be well determined. In the face of these good authorities, the plates show no change beyond the limit of accidental error, the mean residuals from the three plates being ±0.05, ±0.05, and ±0.06 mag. respectively, while for the three comparison stars the residuals on plate 250 are ±0.06, ±0.04, and ±0.04 mag.

The data for *32* and the comparison stars are given in the following table:

	No. *B. D.*		1855		Mags.	
		Mag.	R. A.	Dec.	Harvard[1]	Photog.
32..........	+64° 127	5.9	$1^h\ 2^m\ 21^s$	+64° 13′.3	5.46	....
B..........	64 129	7.4	1 3 18	+64 13.8	7.46	7.38
C..........	63 149	6.0	1 2 4	+63 25.5	5.48	5.48
D..........	63 147	7.8	1 1 15	+63 24.5	....	6.95

Four plates were taken of this star:

No. 249	1905 Oct. 6 from $13^h\ 0^m$ to $17^h\ 0^m$	G. M. T.	17 exposures	1^m
No. 250	Oct. 20 from 12 47 to 16 47	G. M. T.	17 exposures	1
No. 271	Nov. 9 from 11 40 to 18 40	G. M. T.	22 exposures	30^s
No. 322	Dec. 7 from 12 1 to 16 1	G. M. T.	16 exposures	45

TABLE VII

32 CASSIOPEIAE (Plate 250)

Mags.: B=7.38, C=5.48, D=6.95, *b*=10.00

Star		B			C			D			32		
	a	Diam.	Mag.	Res.	Diam.	Mag.	Res.	Diam.	Mag.	Res.	Diam.	Mag.	Res.
1....	8.720	136	7.38	+ 1	214	5.42	− 6	148	7.02	+ 6	208	5.54	+ 2
2....	8.725	137	7.36	− 2	209	5.52	+ 4	151	6.94	− 2	214	5.42	−10
3.....	8.570	130	7.43	+ 6	206	5.43	− 5	145	6.96	0	202	5.52	0
4....	8.559	132	7.35	− 2	207	5.40	− 8	141	7.07	+11	200	5.55	+ 3
5....	8.353	124	7.42	+ 5	194	5.48	0	139	6.92	− 4	196	5.43	− 9
6....	7.935	103	7.44	+ 7	176	5.48	0	127	6.89	− 7	178	5.43	− 9
7....	7.622	103	7.49	+12	166	5.42	− 6	118	6.90	− 6	158	5.63	+11
8....	8.739	136	7.40	+ 3	214	5.44	− 4	150	6.98	+ 2	205	5.62	+10
9....	8.210	122	7.35	− 2	188	5.47	− 1	132	7.00	+ 4	198	(5.24)	....
10....	8.054	110	7.34	− 3	178	5.50	+ 2	126	6.98	+ 2	170	5.55	+ 3
11....	8.383	130	7.24	−13	193	5.53	+ 5	136	7.05	+ 9	195	5.48	− 4
12....	8.316	123	7.42	+ 5	192	5.48	0	138	6.92	− 4	190	5.53	+ 1
13....	8.631	136	7.30	− 7	204	5.54	+ 6	146	6.99	+ 3	205	5.51	− 1
14....	8.266	126	7.26	−11	185	5.59	+11	135	6.96	0	184	5.62	+10
15....	8.139	118	7.35	− 2	178	5.54	+ 6	130	6.93	− 3	185	5.40	−12
16....	8.247	...	....	....	190	5.46	− 2	134	6.98	+ 2	188	5.50	− 2
17....	8.168	118	7.45	+ 8	186	5.47	+ 1	134	6.90	− 6	184	5.52	0
Means.....			7.37	± 6		5.48	± 4		6.96	± 4		5.52	±5

[1] Photometric magnitudes from Harvard *Annals*, 24.

TABLE VIII

PHOTOGRAPHIC MAGNITUDES OF *32 CASSIOPEIAE*

1905. October 6				October 20			November 9		
Plate 249				Plate 250			Plate 271		
No.	G. M. T.	Mag.	Res.	G. M. T.	Mag.	Res.	G. M. T.	Mag.	Res.
1.........	$13^h\ 00^m$	5.43	− 8	$12^h\ 47^m$	5.54	+ 2	$11^h\ 40^m$	5.46	− 6
2.........	13 15	5.53	+ 2	13 03	5.42	−10	11 59	5.49	− 3
3.........	13 30	5.38	−13	13 17	5.52	0	12 20	5.42	−10
4.........	13 45	5.50	− 1	13 32	5.55	+ 3	12 41	5.50	− 2
5.........	14 00	5.50	− 1	13 47	5.43	− 9	13 00	5.45	− 7
6.........	14 15	5.60	+ 9	14 02	5.43	− 9	13 20	5.58	+ 6
7.........	14 30	5.51	0	14 17	5.63	+11	13 41	5.60	+ 8
8.........	14 45	5.49	− 2	14 32	5.62	+10	14 03	5.52	0
9.........	15 00	5.56	+ 5	14 47	....	....	14 22	5.64	+12
10.........	15 15	5.58	+ 7	15 02	5.55	+ 3	14 42	5.54	+ 2
11.........	15 30	5.52	+ 1	15 17	5.48	− 4	15 00	5.44	− 8
12.........	15 45	5.54	+ 3	15 32	5.53	+ 1	15 21	5.47	− 5
13.........	16 00	5.60	+ 9	15 47	5.51	− 1	15 42	5.43	− 9
14.........	16 15	5.42	− 9	16 02	5.62	+10	16 00	5.54	+ 2
15.........	16 30	5.45	− 6	16 17	5.40	−12	16 20	5.44	− 8
16.........	16 45	5.60	+ 9	16 32	5.50	− 2	16 41	5.56	+ 4
17.........	17 00	5.44	− 7	16 47	5.52	0	17 00	5.50	− 2
18.........	......	....	....	......	....	....	17 21	5.64	+12
19.........	......	....	....	......	....	....	17 40	5.56	+ 4
20.........	......	....	....	......	....	....	18 00	5.60	+ 8
21.........	......	....	....	......	....	....	18 20	5.62	+10
22.........	......	....	....	......	....	....	18 40	5.42	−10
Means...		5.51	± 5		5.52	± 5		5.52	± 6

These plates were reduced with the formula $M = a - b \log D$. Table VII shows the details of the reductions, giving the photographic magnitudes of the comparison stars at the head of the table, also the constant b of the plate. The constant a differs somewhat from one exposure to another, and is therefore tabulated in the second column. The remaining columns give for each star the diameter in thousandths of a millimeter, the resulting magnitude and the residual from the mean at the foot. The range for 32, the suspected variable, is from 5.40 to 5.63, the mean residual being ± 0.05, practically the same as for the other three stars. Table VIII gives the times, magnitudes, and residuals for the three plates, the results being shown graphically in Fig. 1.

To test the question, raised by Yendell, whether the light-changes are confined to the visual rays which do not strongly affect the ordi-

nary photographic plate; a series of sixteen exposures was made December 7, 1905, on a Cramer Isochromatic plate, extending from $12^h\ 1^m$ to $16^h\ 1^m$, Greenwich Mean Time, with the following results:

Range, from 5.42 to 5.57 mag.
Mean, 5.48 mag.
Average residual, ± 0.04 mag.

Excellent seeing gave better images and smaller residuals than usual. The plate, therefore, fails to confirm this hypothesis.

YERKES OBSERVATORY,
December 1905

MINOR CONTRIBUTIONS AND NOTES.

REPLY TO RECENT STATEMENTS BY M. DESLANDRES[1]

I regret exceedingly the necessity of discussing a question of priority, but the repeated statements of M. Deslandres leave no alternative. My reply, however, will be brief.

I am quite content to leave the question of priority in the use of the spectroheliograph to the judgment of those who are acquainted with the facts. In 1894 the French Academy of Sciences awarded me the Janssen medal for the construction and use of the first successful spectroheliograph. In the statement of the reasons for the award (*Comptes Rendus*, **119**, 1068, 1894) no reference is made to M. Deslandres. This might reasonably be considered to settle the matter. However, if confirmation of the opinion of the Academy was needed, it has since been supplied by the award of the Rumford, Draper and Gold Medals of the American Academy of Sciences, the National Academy of Sciences, and the Royal Astronomical Society, respectively. In each case the first successful application of the spectroheliograph was named as the principal reason for conferring the medal.

Although M. Deslandres did not use a spectroheliograph until more than a year after my first successful work with this instrument at the Kenwood Observatory, his observations of the *spectra* of the calcium flocculi were commenced in 1891, almost simultaneously with my own investigations of these spectra. Before 1893, when he also obtained a spectroheliograph, which he has since used with marked success, M. Deslandres devoted special attention to a study of the K line in successive sections of the Sun's disk. The *spectrograph* employed for this purpose was moved a short distance between each exposure, but the exposures were made when the instrument was at rest, and the resulting photographs are photographs of *spectra*. This method is extremely useful, as it gives the means of determining the motion of the calcium vapor in the line of sight at many points on the disk, and in the chromosphere and prominences surrounding the Sun. But a spectrograph thus employed is in no sense a spectroheliograph, although a wide second slit limits the spectral region photographed to the K line and a few lines in its immediate neighborhood.

[1] See *Bulletin Astronomique*, August 1905, and various papers in the *Comptes Rendus*.

Of course, a spectroheliograph can be used to observe or photograph spectra: both solar and stellar spectra have been photographed with our new instrument on Mount Wilson. But when employed for such work, a spectroheliograph is for the time being a spectroscope or spectrograph, since the principle of continuous relative motion of solar image and slit, essential in a spectroheliograph, is lacking. Photographs of the K line in successive sections of the disk were made at the Kenwood Observatory in 1891, before the spectroheliograph was completed; they are still frequently taken in connection with our other solar work.

As I have given the fullest recognition in my papers to those who preceded me in suggesting the principle of the spectroheliograph, including Professor O. Lohse, who actually built and experimented with such an instrument, I see no reason why I should be suspected of a desire to obtain credit properly due M. Deslandres.[1]

[1] M. Deslandres complains (in the *Bulletin Astronomique*) that his papers have not been published in the *Astrophysical Journal*. He alone is responsible for this, as the editors have neither been favored with his manuscripts nor informed of his desire for such publication.

George E. Hale.

SOLAR ECLIPSE OF AUGUST 30, 1905

The eclipse observers from Kirkwood Observatory, Indiana University, Bloomington, Indiana, were located at Almazan, Spain, a small town northeast of Madrid in the Province of Soria. The party consisted of Professor W. A. Cogshall, of Indiana University, Messrs. E. C. Slipher, F. A. Crull, and C. J. Bulleit, students of the university, Professor A. F. Kuersteiner, Mrs. Miller, and myself. We were assisted, in the manipulation of our instruments on the day of the eclipse by Mr. and Mrs. Charles W. Thompson of California, and Señores Francisco Jodra, Louis Nebot, Victor Jiemenez, and Esteban Milla, of Almazan. The approximate position of the station is $\phi = 41° 30'$, $\lambda = 13^m 56^s$ W. of Greenwich.

The observations planned were: (1) Photographs of the corona; (2) a photographic search for intra-mercurial planets; (3) a photograph of the spectrum of each of the flashes, and a photograph of the spectrum of the corona during totality.

The equipment for photographing the corona consisted of four cameras. The diameter of the objective of the principal one is nine inches and its focal length is sixty feet. This instrument was mounted horizontally and fed with a coelostat. A light-tight tube, the outer and inner walls of which were of white canvas and building paper respectively, and which were

separated four inches, led from the objective to a dark room in which the plates were exposed. Neither the plates nor the lens was in contact with the tube. The entire instrument was covered with an A tent of white canvas. The plate-holders containing the plates were fastened to a large hexagon, which the operator could revolve at will upon an axis which was parallel to the Earth's axis. It was provided with a stop which enabled the operator to bring the plates for the successive exposures quickly and accurately into position. All the slides had been drawn from the plate-holders before totality began. The hexagon, as well as most of the mechanical parts of the coelostat, was designed and constructed by Professor Cogshall. Six exposures were made in this camera, of duration one-half-second, two seconds, forty seconds, one minute, fifteen seconds, and one-half second. The plates used were Seed's 27, Gilt Edge, heavily backed. Four exposures were made in a camera having an objective of four inches diameter and of fifty inches focal length. Five exposures were made with a portrait lens of aperture five inches and focal length twenty-eight inches, and three with an old tintype lens of eight inches focal length. The plates used in these cameras were either Seed's 27 or lantern-slide plates. These cameras, together with a spectroscope, were mounted on a polar axis.

The weather on the day of the eclipse was disappointing. For two hours before totality the entire sky was covered by light, though unbroken, clouds. At the time of totality, however, the clouds in the immediate vicinity of the Sun appeared to break away, and the inner corona shone through light, drifting clouds. No clear sky was visible, however, within several degrees of the Sun, neither *Mercury* nor *Regulus* could be seen from this station. During the morning a moderate wind prevailed, the general direction being W. N. W. The first contact was, neglecting seconds, at 11:41. The weather conditions during the eclipse, as observed and recorded by Mr. Thompson were as follows:

Local M. Time	Temperature	Direction of Wind	
11:41....	First	contact	Very slight wind
12:00....	18°.5 C.	N. W.	Very slight wind
12:15....	18.2	N. W.	Very slight wind.
12:30....	17.1	W. by S.	Wind dying away
12:45....	16.1		No wind
12:59....	Totality	begins	No wind
1:03....	Totality	ends	No wind
1:06....	15.0	S. W.	Very slight wind
1:15....	15.0	W.	
1:30....	15.5	W.	
1:45....	16.0	W. N. W.	Wind increasing
2:00....	16.5	W. N. W.	Brisk wind
2:15....	17.2	W. by N.	Brisk wind
2:21....	Eclipse	ends	

Considering the weather conditions, our plates are very satisfactory. The shortest exposure, showing the prominences, suffered very little. The very bright group on the eastern edge of the Sun is particularly well defined, and the negatives made of it with the long-focus camera hold a wealth of detail. The longer short exposures with the long-focus as well as the short-focus cameras show considerable coronal detail, while the longest exposures have that part of the corona uncovered by the clouds much over-exposed, while the clouds made it impossible to register any extended streamers. All the plates lack the definiteness that would have resulted from good seeing. The longest extension of the corona that we obtained was about three-fourths the Sun's diameter.

The apparatus used for the search for intra-mercurial planets consisted of six cameras of 136 inches focal length, four of which had an aperture of three and one-half inches, and two an aperture of three inches All were mounted on the same polar axis. They were mounted in pairs each pair covering in duplicate a region six and one-half degrees square, so that the three pairs covered in duplicate a region along the Sun's equator twenty degrees long and six degrees wide. By a series of experiments we had found that a plate exposed in one of these cameras for three minutes and forty-five seconds, at a time when the sky was as dark as it was estimated it would be at the time of totality, though fogged somewhat by the skylight, would show more and fainter stars than if exposed for a shorter time. We had made exposures varying from one to four seconds, in the vicinity of *Regulus*, when it was near the meridian, beginning just after *Polaris* was visible to the eye. We decided to expose the plates in these cameras for three minutes and twenty seconds. These plates are pretty heavily fogged, as one would expect from a sky covered with bright clouds, but not so badly as to obscure faint star-images. I believe that a plate of the sensitiveness of the Seed's 27, which we used, can be exposed three minutes without serious fog at a time of a total solar eclipse. Our sky was so cloudy that it is unreasonable to expect star-images on these plates. We examined two of them hurriedly (the ones on which *Regulus* should have appeared), but found no star-images. The photograph of the corona on one of the intra-mercurial plates showed longer extension than on any other plate we exposed—due perhaps to the shifting of the clouds during the long exposure.

The corona impressed me as being brighter than in 1900. The effect on the clouds of the light from the eclipsed Sun was peculiarly striking, and from a spectator's point of view was very beautiful.

JOHN A. MILLER.

KIRKWOOD OBSERVATORY,
Bloomington, Ind.
November 9, 1905.

DIFFRACTION GRATING REPLICAS

SECOND NOTE

In a previous paper[1] the writer described the process in use by him for the manufacture of replicas of Rowland's plane diffraction gratings. The present note is a description of a modification of that process, which offers a simplified method of producing good casts.

The original grating is flowed with the amyl acetate collodion and dried in the manner previously described; it is then placed in distilled water until loosened by contraction, and wiped dry. The stripping is performed as usual, and the edges of the cast are trimmed with sharp scissors close up to the ruled surface. This trimming should be done while the replica is held by the forceps, as it is strongly electrified by the stripping, so that minute particles of dust are attracted to the surface of the cast, and adhere thereto, being removable only with difficulty. A perfectly clean and polished glass plate is then flooded with filtered distilled water; and, while the plate still holds a little pool of liquid, the film is gently lowered into contact, carefully centered, and the plate is tilted up. A very gentle even pressure by the velvet rubber frees the cast from surplus water, and the edges are immediately cemented.[2]

The mounting may be either face up or down, as may be desired.

After the edges have been cemented down, the mounted replica may be dried by heat, beginning gently and increasing gradually until a temperature of about 75° C. is reached. In this way the film of water between the glass and the replica is driven off, the film being slightly porous.

If the replica has been mounted face down, it may readily be cemented under a covering glass, following the idea advanced by Ives. Care must be taken, however, that no particles of dust or other foreign substance

[1] *Astrophysical Journal*, **22**, 123, 1905.

[2] Since the writing of this present note there has come to hand *Nature* of November 23, 1905 (**73**, 79) containing a brief article by Mr. Thorp, somewhat in the nature of a reply to my former paper. In this article Mr. Thorp states that he strips and mounts "in a similar manner to Mr. Wallace, but leaving out the gelatin coating, which in my [his] opinion is quite unnecessary." He does not indicate whether or not any other medium is used in this connection.

This idea of mounting by the water method first occurred to the present writer about one year ago and some slight amount of experimental work was performed thereon at that time. However, in the beginning of September, 1905, the work was again taken up and carried through to completion in October; a written statement of the process was made and attested on November 2. In the event of further information confirming the similarity of this water method with that pursued by Mr. Thorp I cheerfully accord to him the priority of use of this process.

have found a lodgment either between the glass and the replica, or in the film itself during the drying, as they will inevitably cause trouble by puncturing the replica and allowing access to the cementing balsam, which, gradually working through the most minute hole, and filling up the grooves, destroys the grating.

Since the publication of the previous paper the author has been informed that the deterioration of the Ives grating alluded to therein is due to this cause, and another grating since obtained shows no sign of deterioration. A correction is also due with reference to Ives' patent, as it now appears that no patent was applied for. The previous statement was based upon information the writer had reason to regard as authoritative.

In mounting by what may be termed the water method, in contradistinction to the former gelatine method, one eliminates at once the very slight difference in refractive index between the replica and the mountant; true, the difference still exists between the replica and the glass itself, but this may be readily overlooked. Experience has shown that, although theoretically open to objection, yet practically, so far as definition is concerned, it is an entirely "negligible quantity." In any event, the similarity in refractive index between the film and mountant (or cement), when adjusted for light of certain wave-length, will not be similarly identical throughout the spectrum. In this connection it may be noted that if a replica be mounted face down upon the gelatine-coated glass, and dried, approximation to the refractive index of the replica is so close that in ordinary daylight the grating effect disappears, and diffraction colors are entirely absent. If examination be made, however, in a spectroscope, with a wide slit and a concentrated beam of light, then very faint first-order spectra are discernible.

Further experimental work was undertaken with the object of determining whether the shrinkage effect was complete with the first part of the process (the stripping) or was continued during the course of the drying. The result of these experiments confirm the latter view.

Measurements were made upon replicas taken from a four-inch and two-inch grating, respectively, which were stripped and mounted under varying conditions, viz.: (1) preliminary bath in water, "sprung" off, and peeled dry; (2) floated off entirely under water; and (3) with prolonged soaking in water. The measurements were made (*a*) while wet, (*b*) partially dry, (*c*) thoroughly dry; (*d*) dried by heat; and (*e*) at normal temperature; (*f*) water mounting and (*g*) gelatine mounting; also (*h*) water mounting, cemented edges, (*k*) water mounting, uncemented edges.

Mean results show that there is a measurable contraction during the drying of 0.016 mm in 35.0 mm.

The particular benefit, therefore, arising from the use of a preliminary coating with gelatine, lies in the fact that once the replica film is mounted thereon it dries without further shrinkage, the gelatine itself drying on glass without contraction in area.

This latter point was determined separately by a series of measurements, for which the writer takes pleasure in acknowledging his indebtedness to Miss F. A. Graves. These measurements upon wet and dry gelatine films, were made with the object of determining any positive shrinkage between the two states. The results obtained show that there is no measurable difference observable, the actual mean being

$$\text{wet} = 7.030 \text{ mm}$$
$$\text{dry} = 7.028 \text{ mm},$$

the difference of 0.002 mm obtained being less than the probable error in setting.

In a series of experiments made upon the influence of temperature upon the collodion film during the time of "casting," it was found that an increase over 21° C. would cause the replica to dry with a more or less matt or reticulated surface. This reticulation increases with the temperature. Lower temperatures varying down to 6° C. appear to exercise no influence upon the film.

Contrary to expectation, a pressure of 200 lbs., continued for ten days, appears to have no direct effect upon the replica. It was supposed that such a continued pressure would result in either a flattening of the ruling, or at least in a changed shape of groove. Careful examination in a spectrophotometer, however, does not show any difference between the half which was subjected to pressure, and that which was not, each half being covered by opaque paper, respectively, when tested.

Through the courtesy of Mr. T. Thorp, of England, the writer has been presented with a grating replica from a 14,438 ruling, and in a letter accompanying the same is informed that the present method of preparing and mounting the casts has been much improved from that in use by him formerly, the air-bubbles (referred to in my former paper) being now entirely eliminated. The replica certainly bears out the statement, being very free from such imperfections and presenting a very clean and brilliant appearance. Mr. Thorp further states that he does not use a preliminary coating with oil before flowing the grating, but makes use of a method

"very little different from" that described by the writer in his previous paper.[1]

[1] Information upon this point was taken from an account of patent specifications (No. 11,466, 1899 T. Thorp) dealing with an improvement on Professor R. W. Wood's diffraction process of color photography, in which occurs the following statement: "A method, non-photographic, of reproducing gratings by smearing the original with a thin oil, such as watchmakers use, and pouring a celluloid solution upon it, allowing it to dry and pulling it off, is also claimed" (*Photography*, August 2, 1900, p. 514).

ROBERT JAMES WALLACE.

YERKES OBSERVATORY,
December 15, 1905.

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed.

Authors are particularly requested to employ uniformly the metric units of length and mass; the English equivalents may be added if desired.

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